



US011594025B2

(12) **United States Patent**
Assouline et al.

(10) **Patent No.:** **US 11,594,025 B2**
(45) **Date of Patent:** **Feb. 28, 2023**

(54) **SKELETAL TRACKING USING PREVIOUS FRAMES**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(21) Appl. No.: **17/240,457**

“U.S. Appl. No. 16/710,980, Non Final Office Action dated Oct. 6, 2020”, 7 pgs.

(22) Filed: **Apr. 26, 2021**

(Continued)

(65) **Prior Publication Data**
US 2021/0248373 A1 Aug. 12, 2021

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Related U.S. Application Data

(63) Continuation of application No. 16/710,980, filed on Dec. 11, 2019, now Pat. No. 11,036,989.

(57) **ABSTRACT**

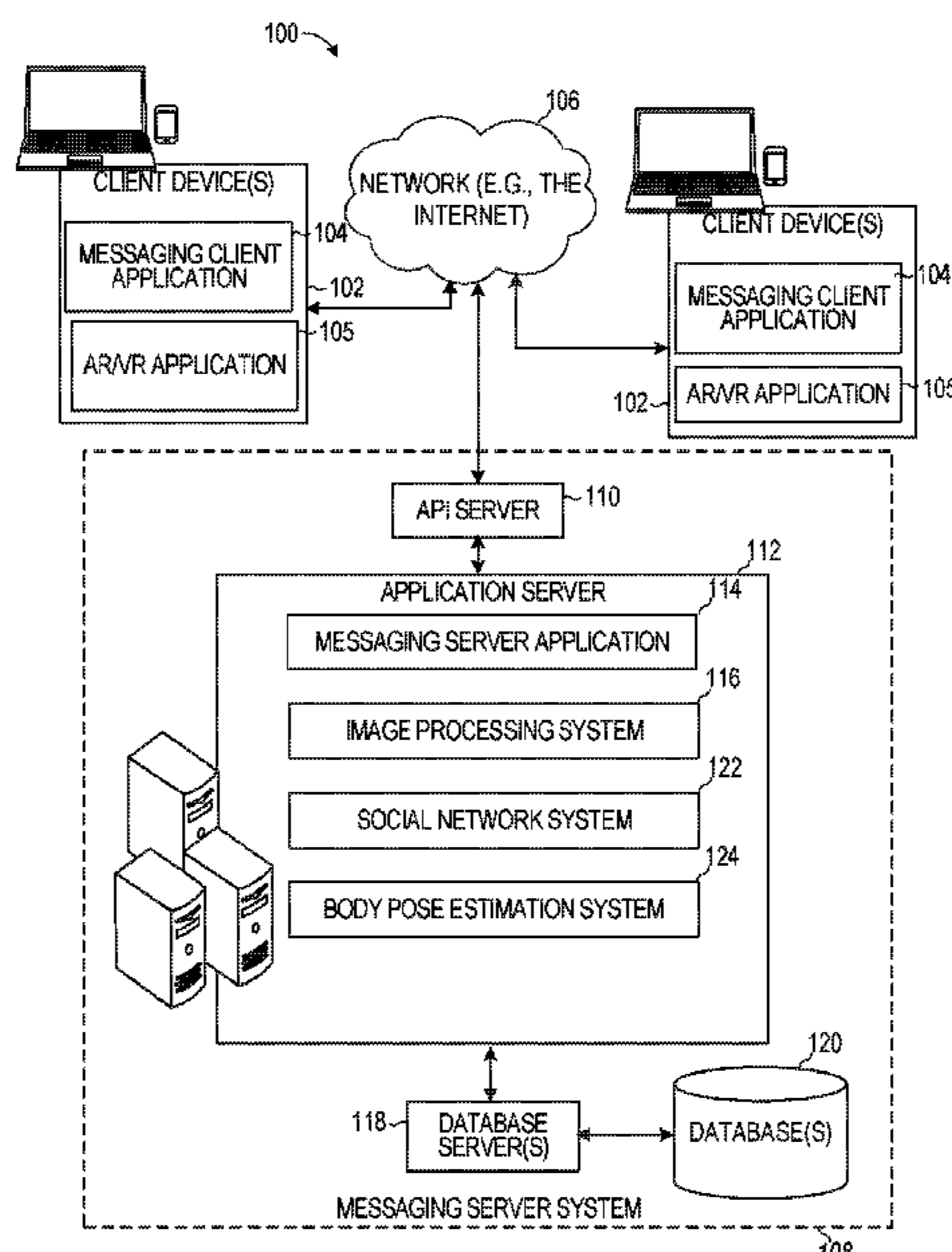
(51) **Int. Cl.**
G06T 17/20 (2006.01)
G06V 20/20 (2022.01)
(Continued)

Aspects of the present disclosure involve a system comprising a computer-readable storage medium storing a program and a method for detecting a pose of a user. The program and method include operations comprising receiving a monocular image that includes a depiction of a body of a user; detecting a plurality of skeletal joints of the body based on the monocular image; accessing a video feed comprising a plurality of monocular images received prior to the monocular image; filtering, using the video feed, the plurality of skeletal joints of the body detected based on the monocular image; and determining a pose represented by the body depicted in the monocular image based on the filtered plurality of skeletal joints of the body.

(52) **U.S. Cl.**
CPC **G06V 20/20** (2022.01); **G06K 9/6256** (2013.01); **G06V 20/46** (2022.01); **G06V 20/647** (2022.01);
(Continued)

(58) **Field of Classification Search**
CPC G06T 13/40; G06K 9/00671
(Continued)

20 Claims, 14 Drawing Sheets



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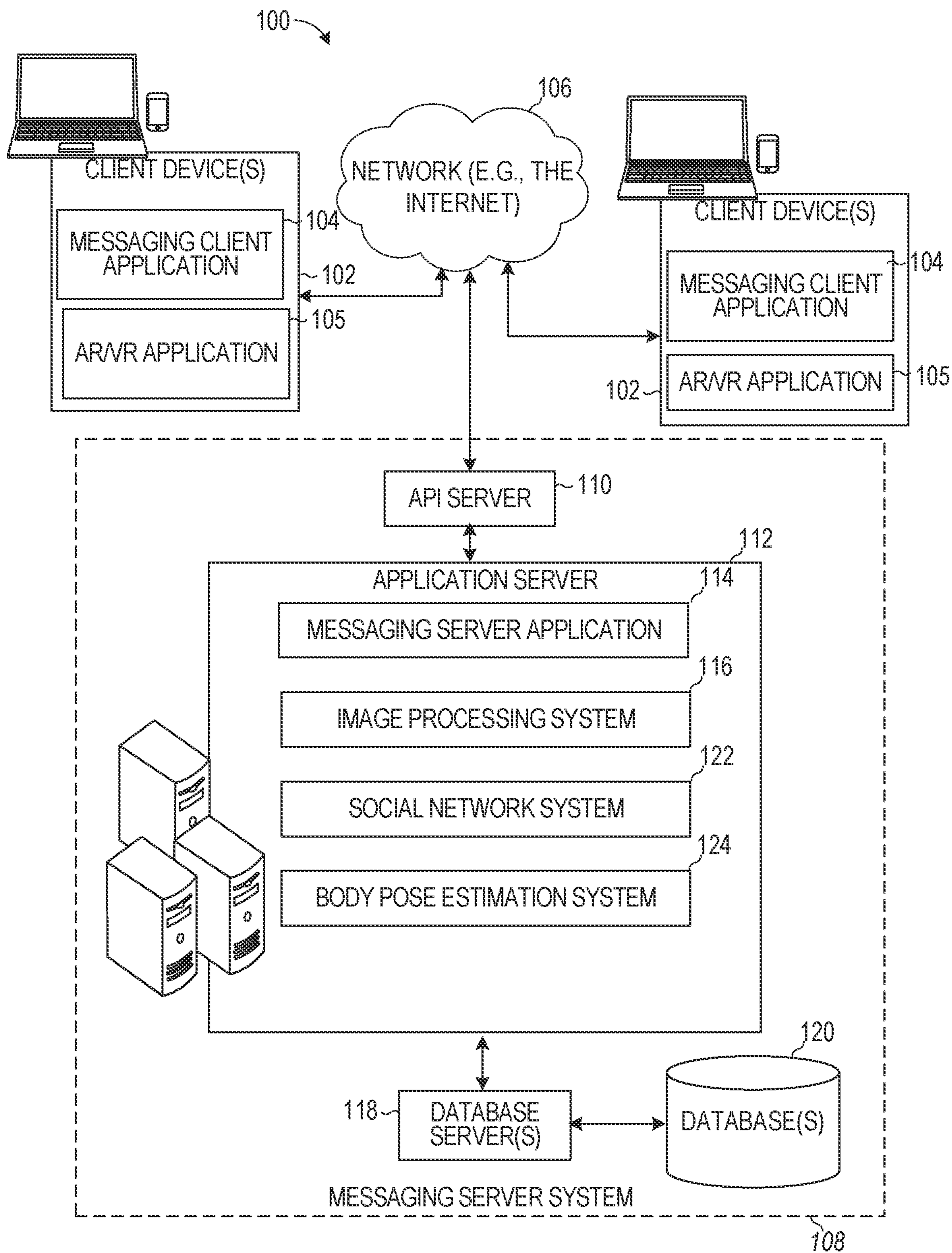


FIG. 1

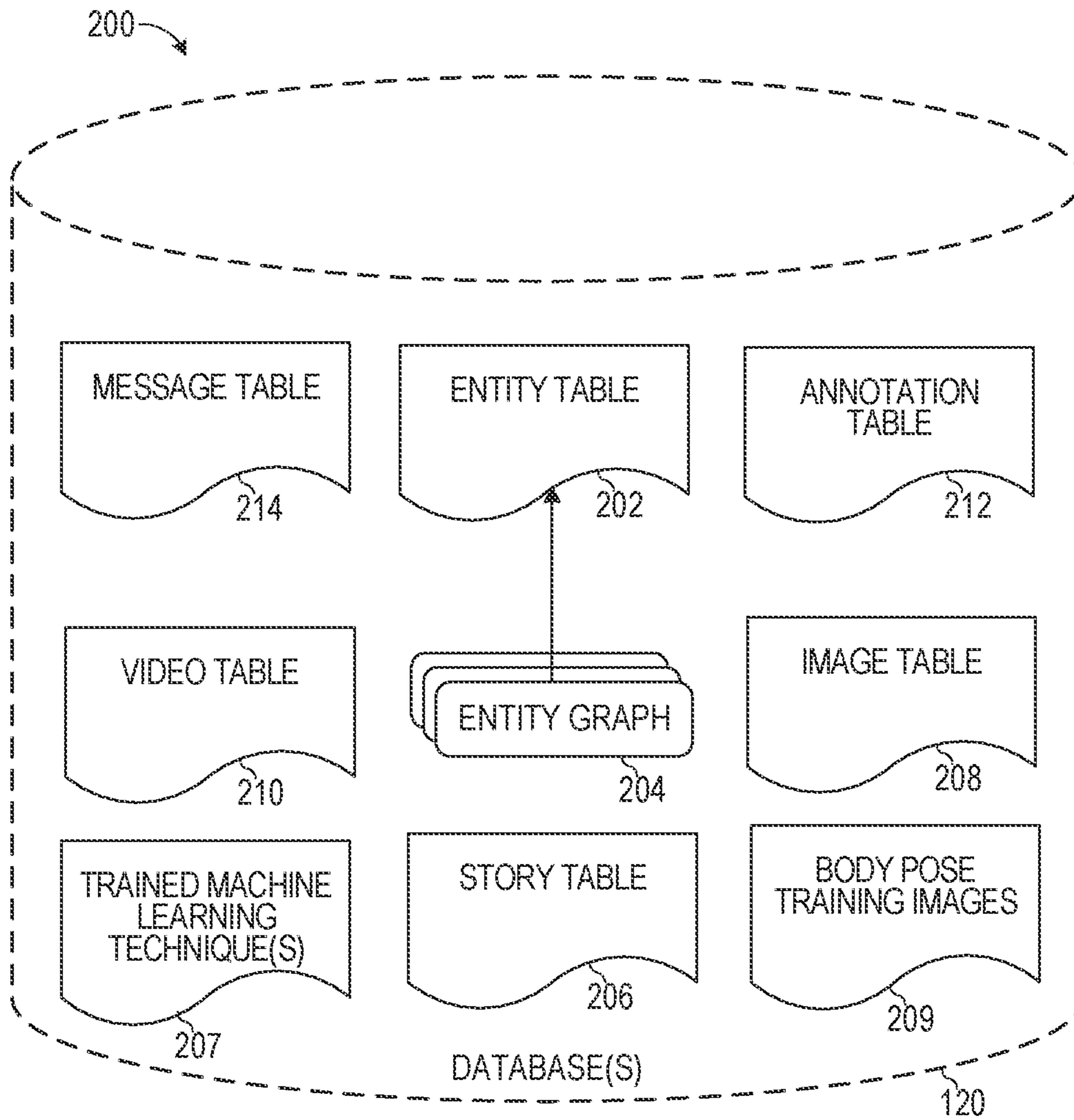


FIG. 2

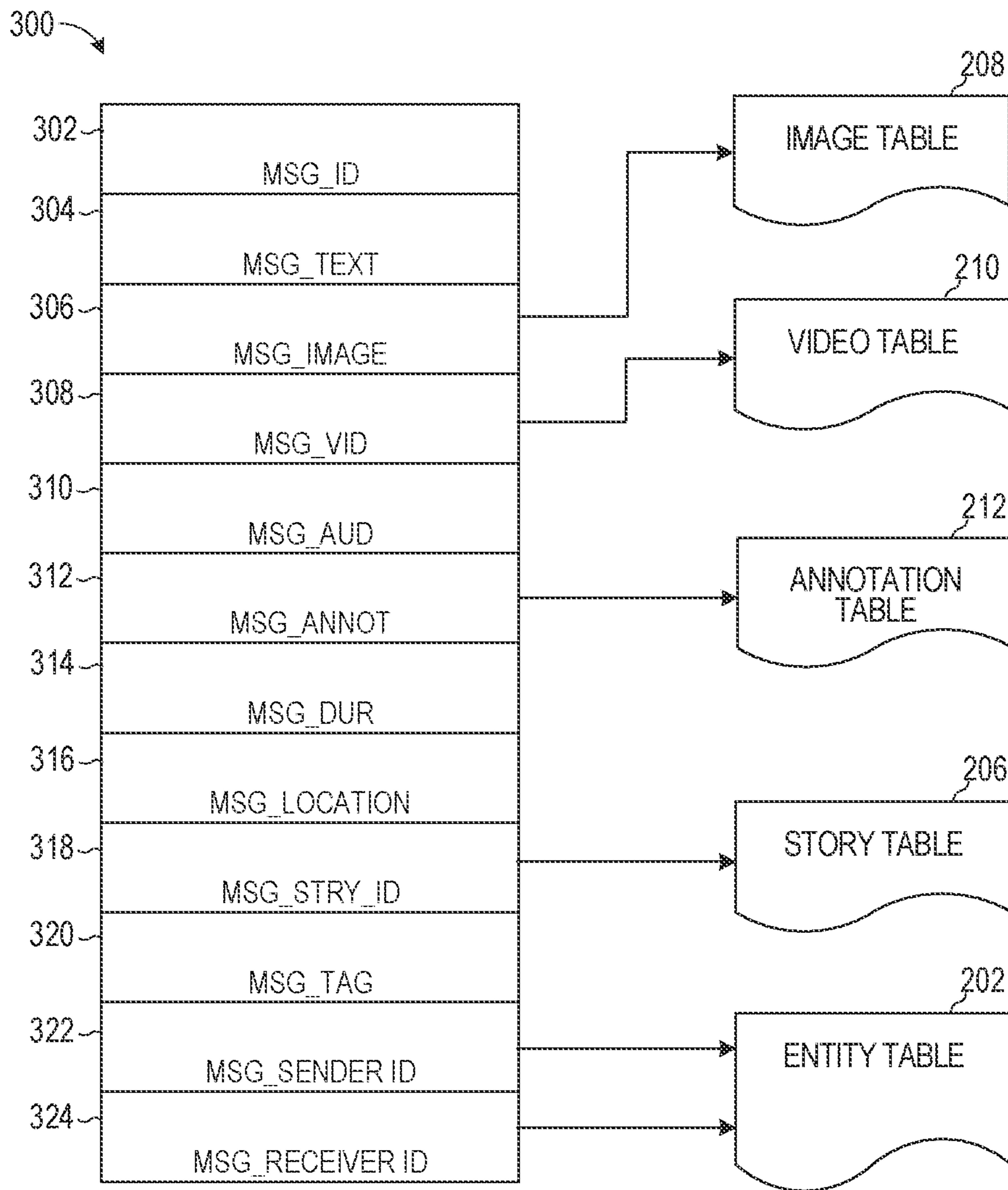


FIG. 3

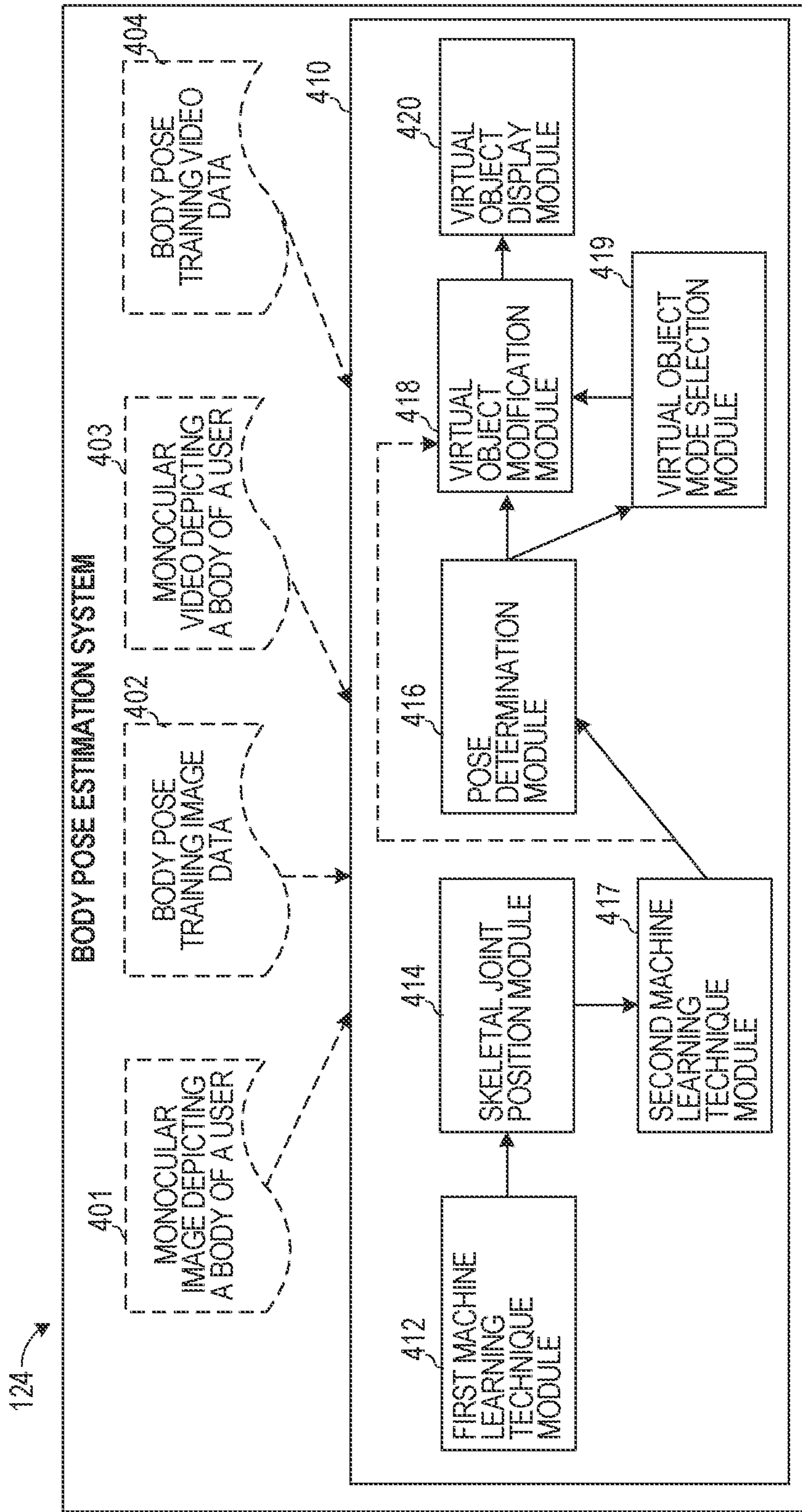


FIG. 4

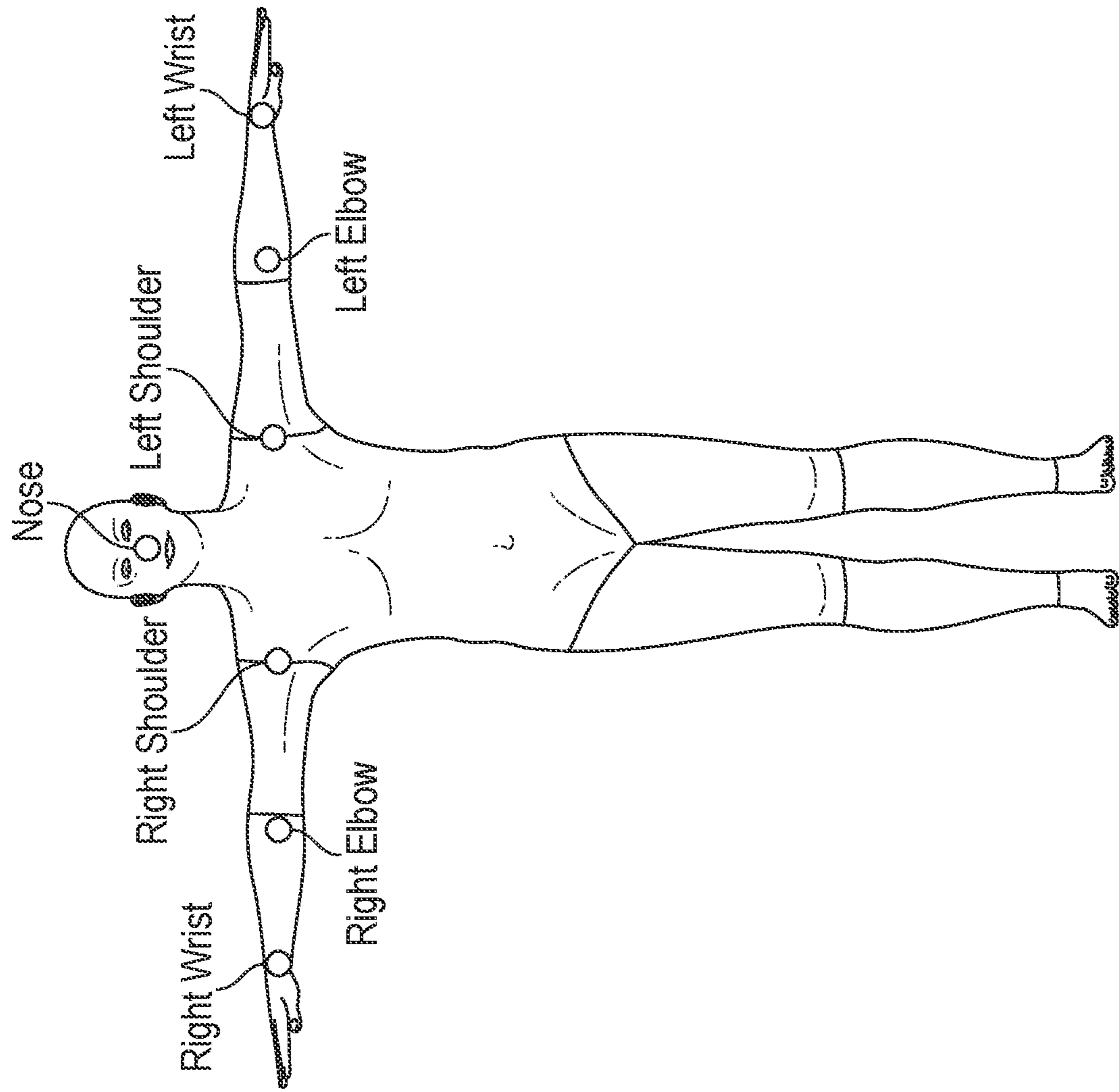


FIG. 5

600

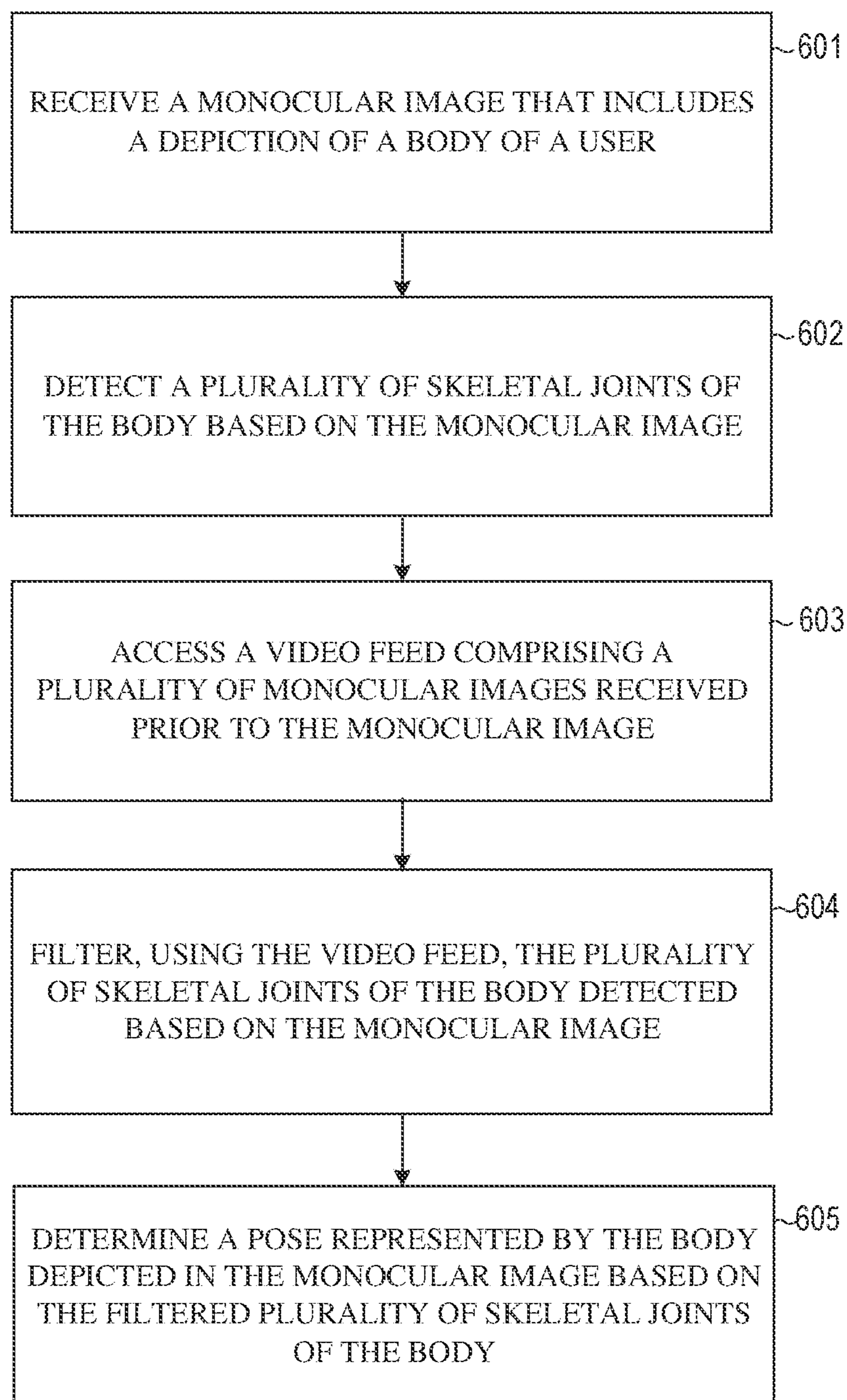


FIG. 6

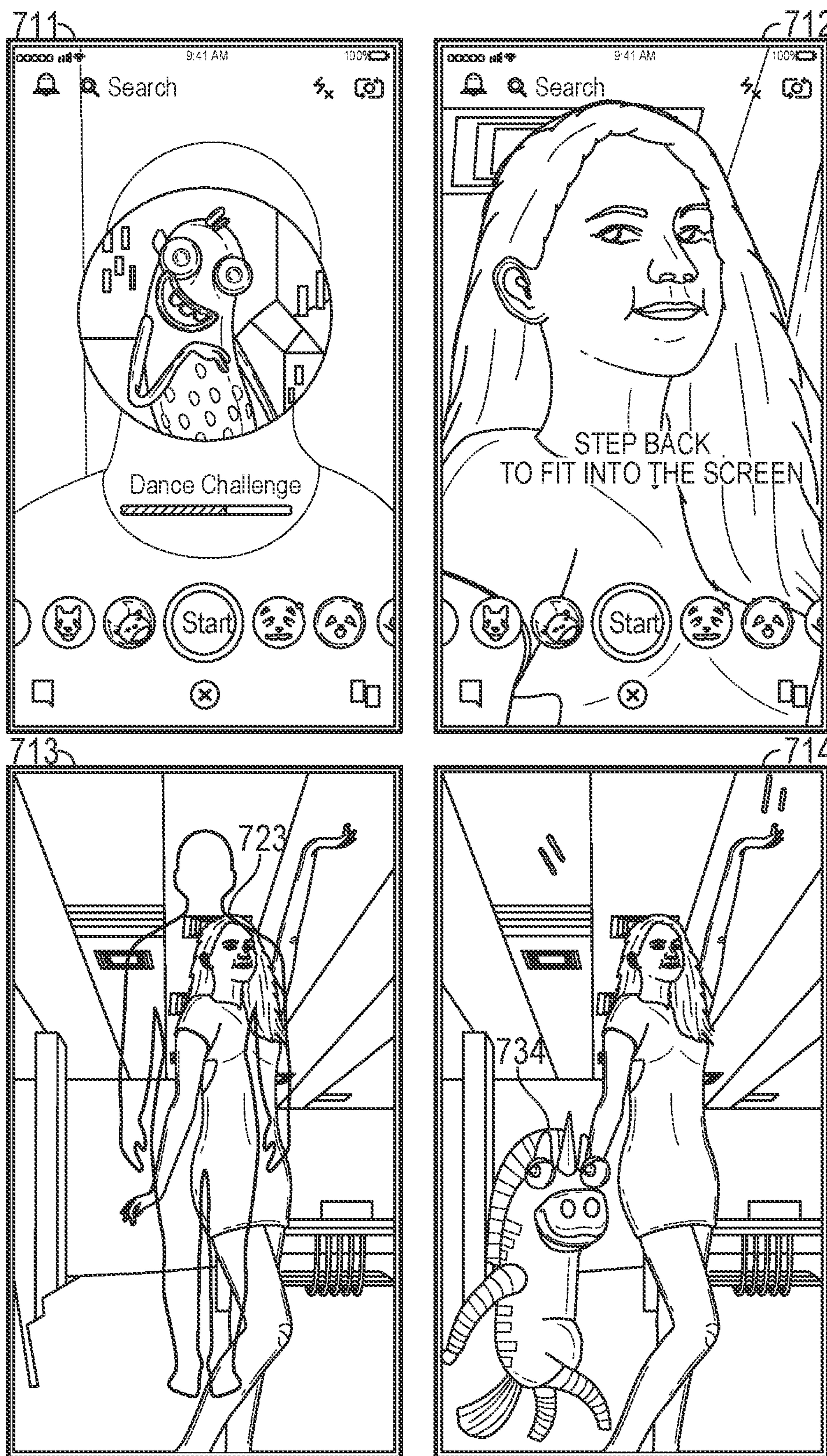


FIG. 7A

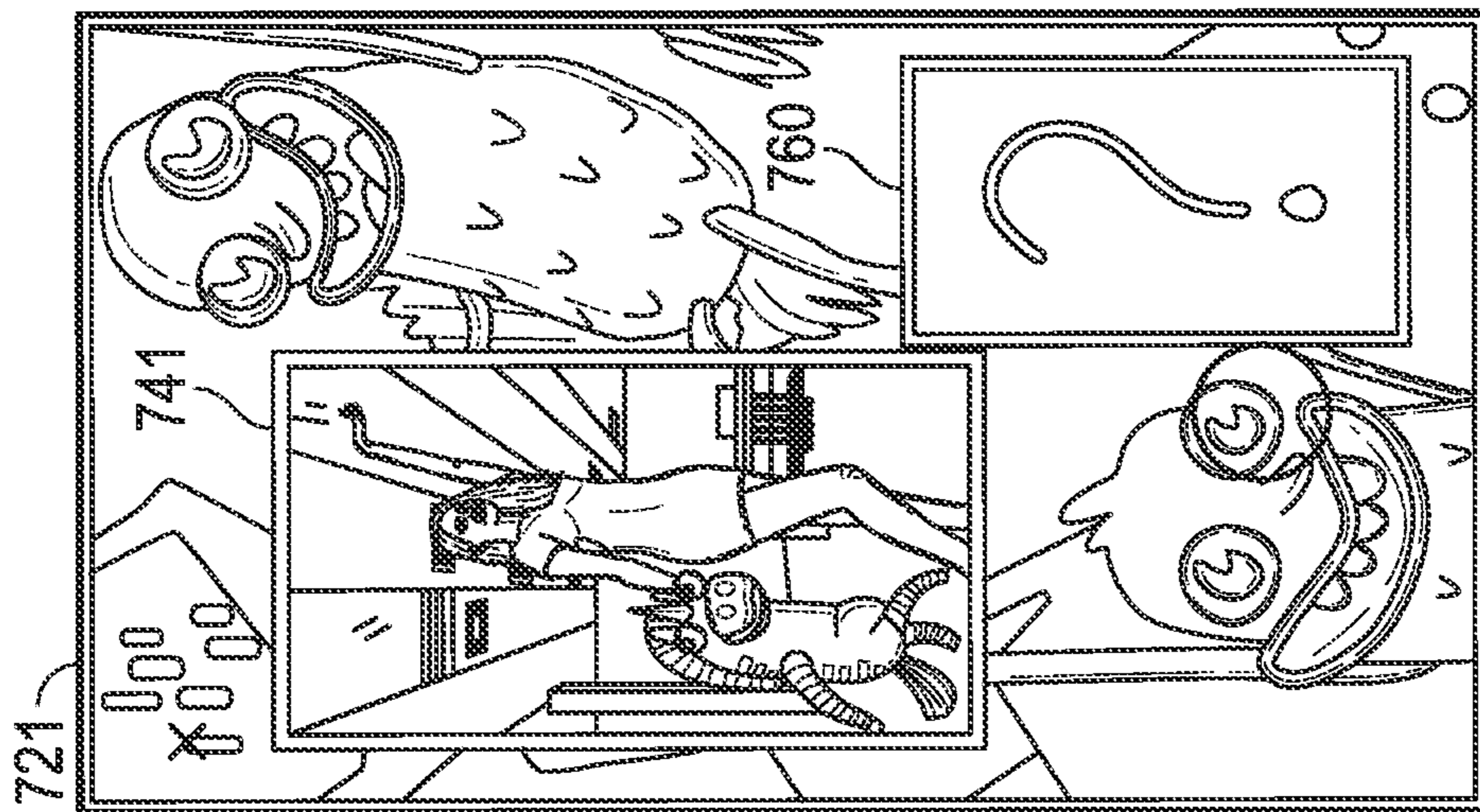
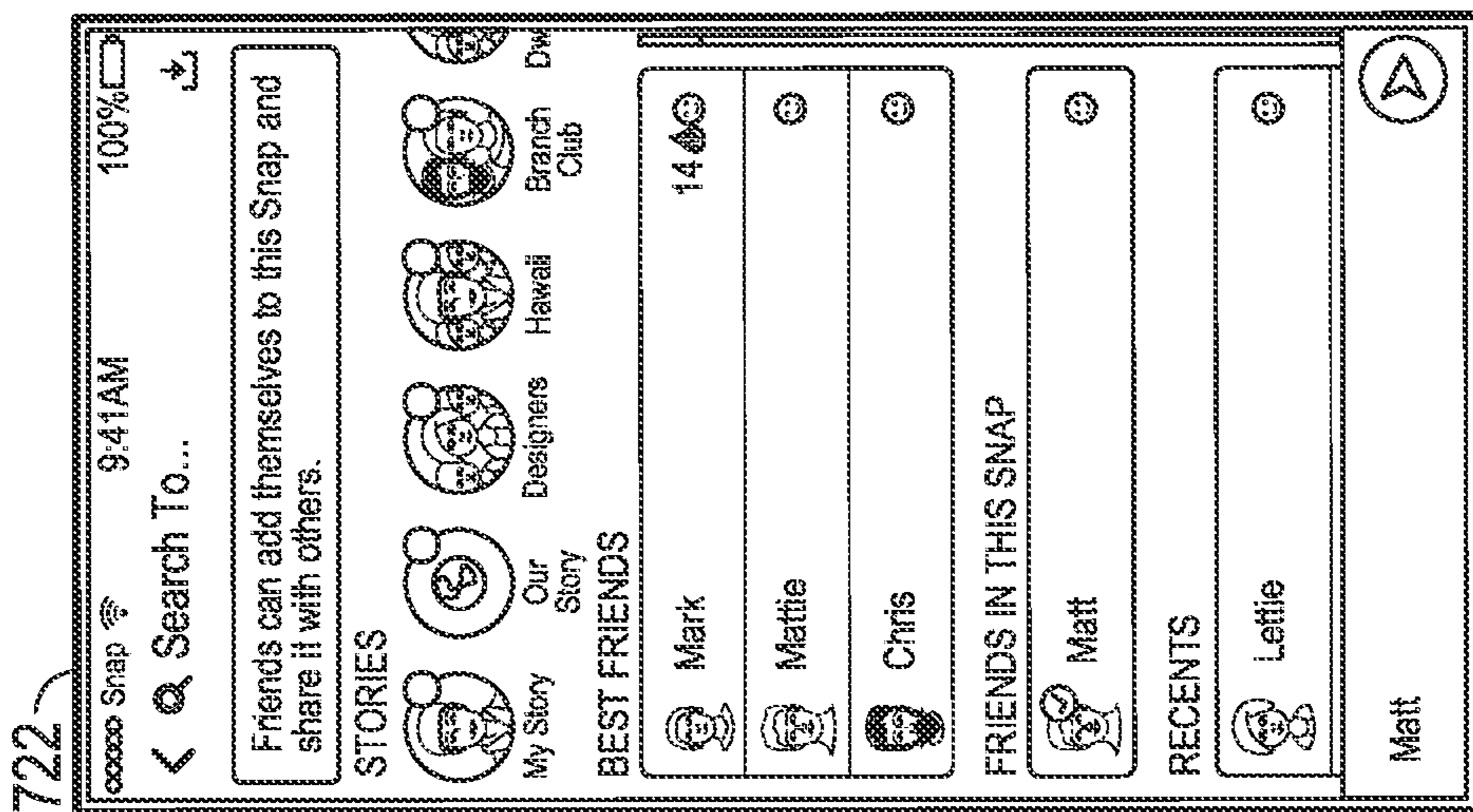


FIG. 7B

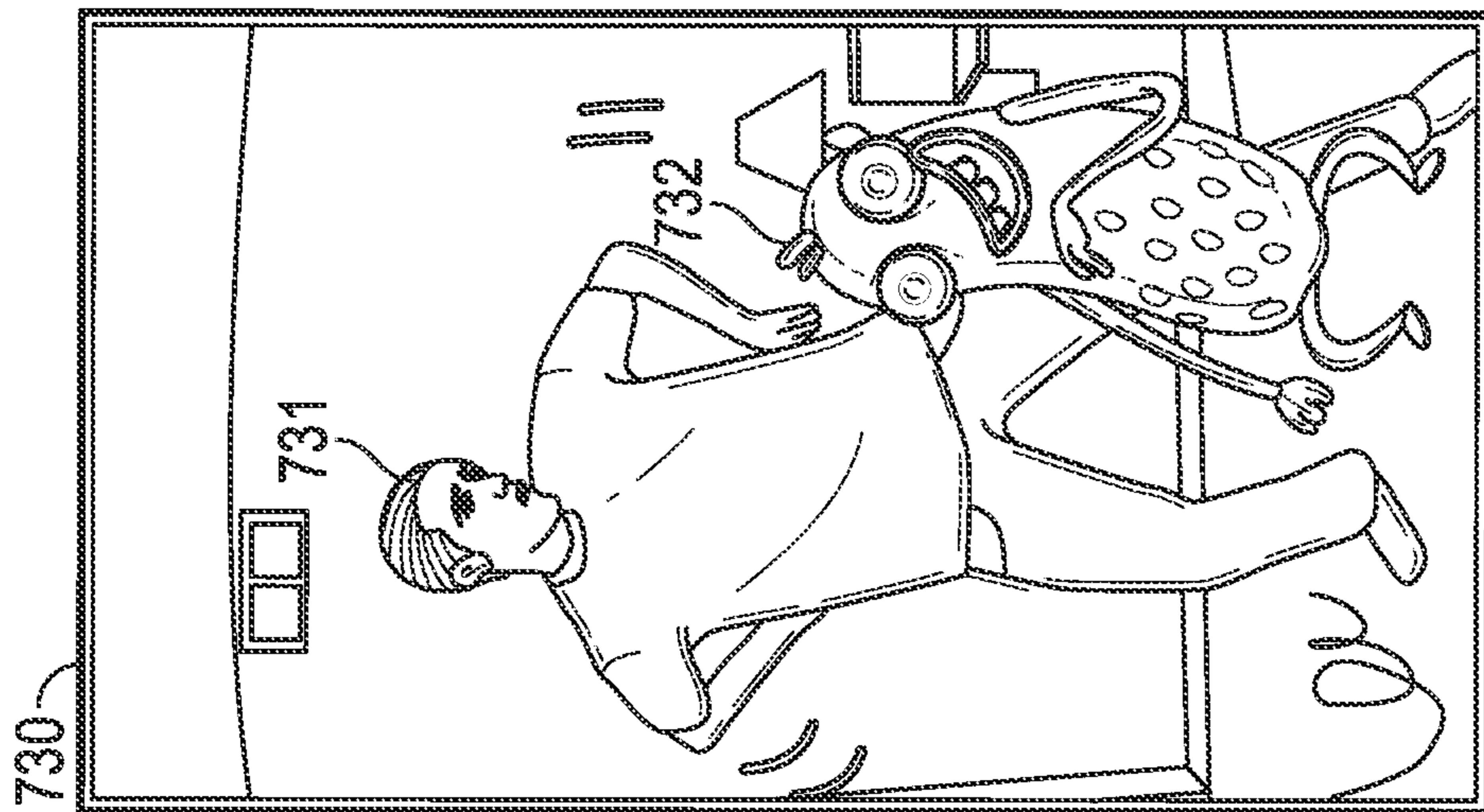
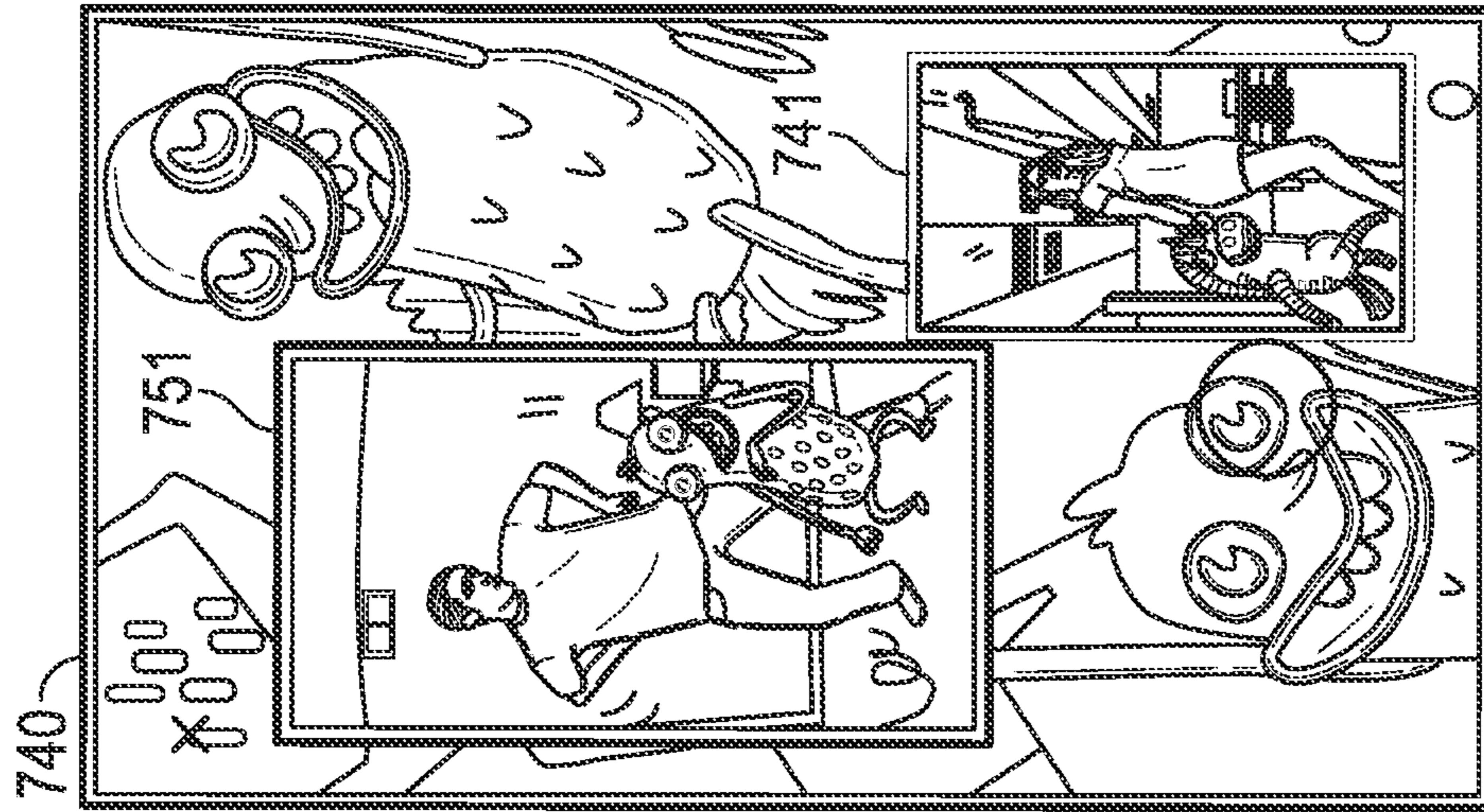


FIG. 70



FIG. 8A

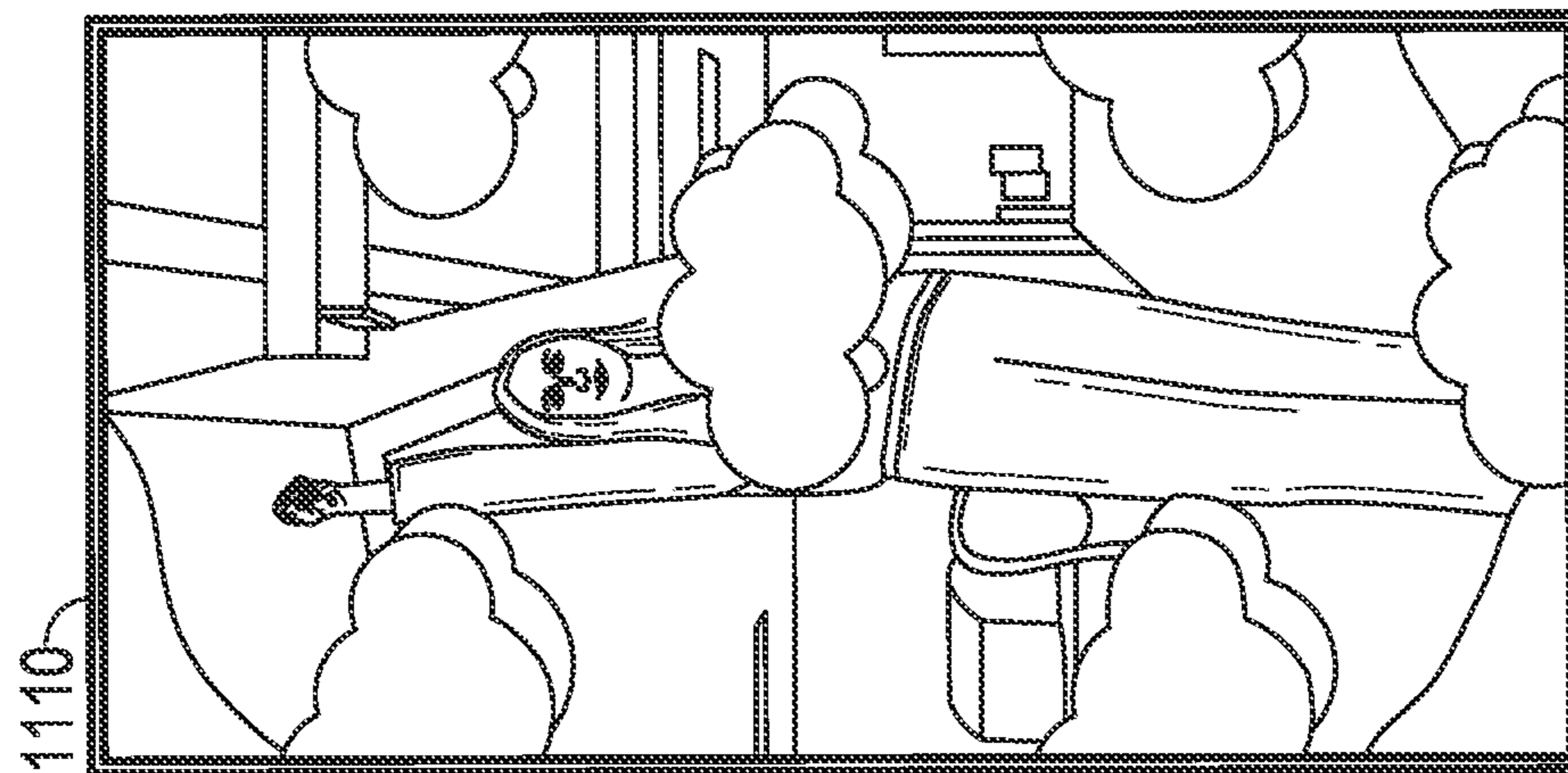
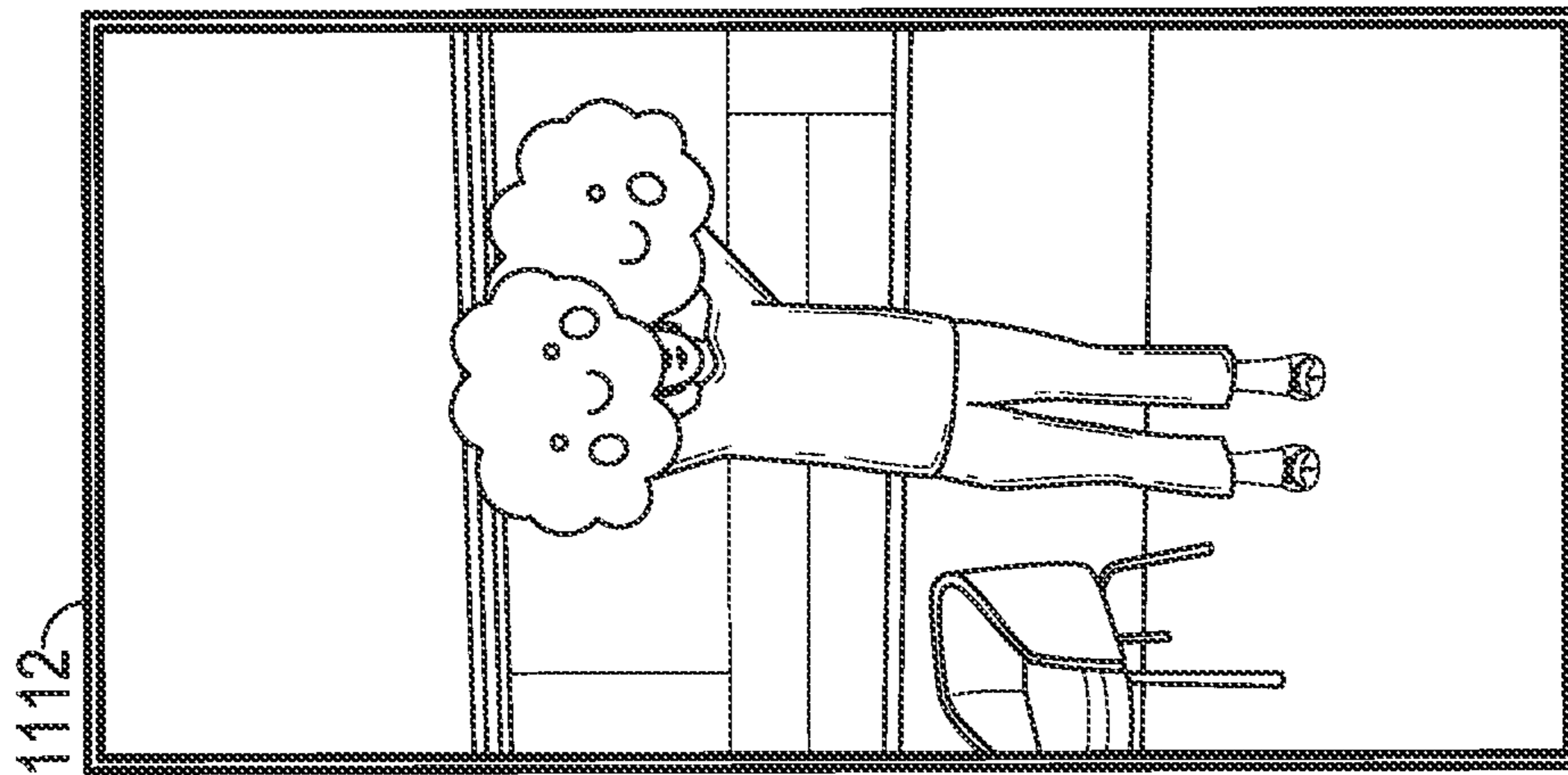
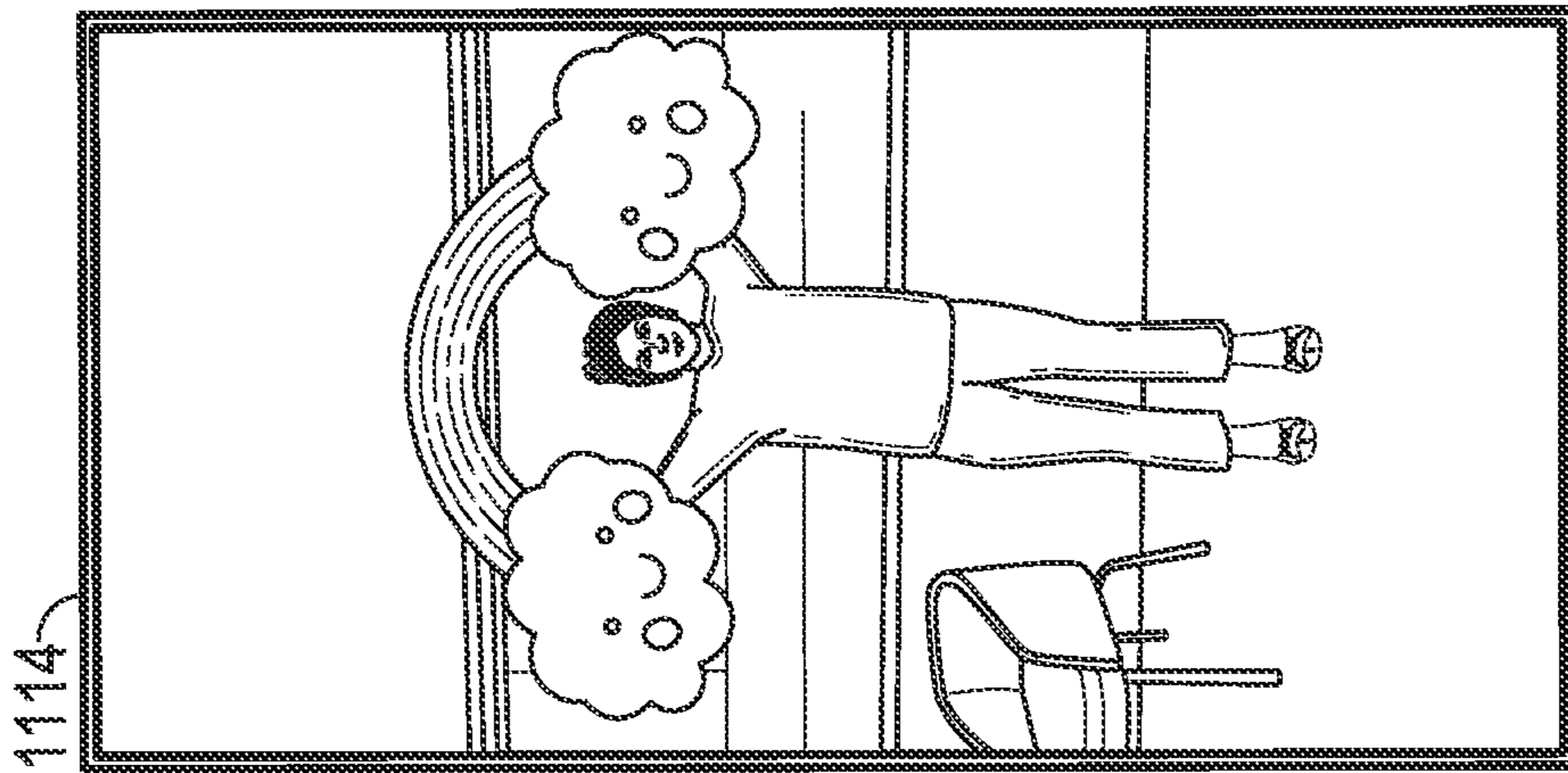


FIG. 8B

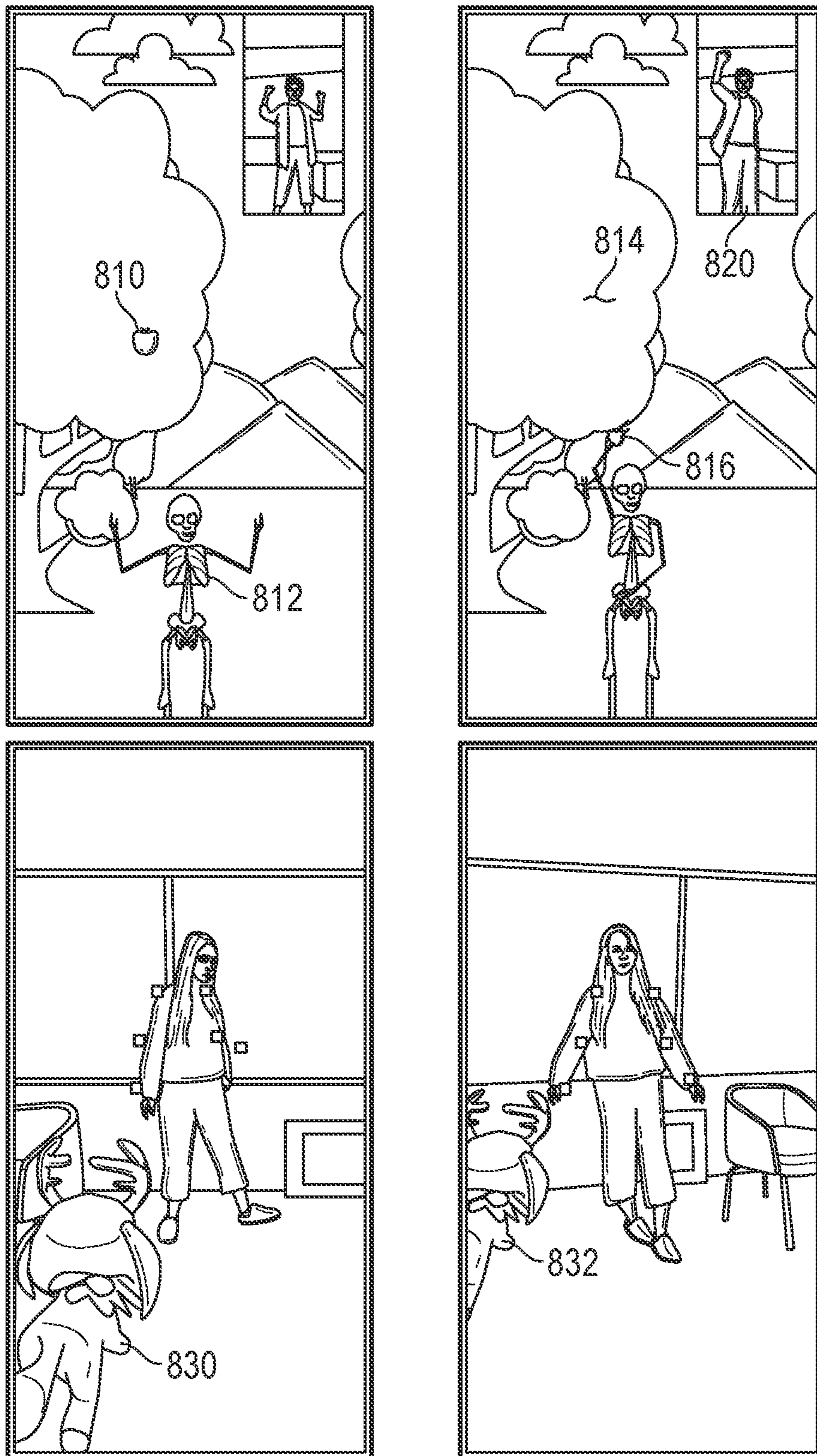


FIG. 8C

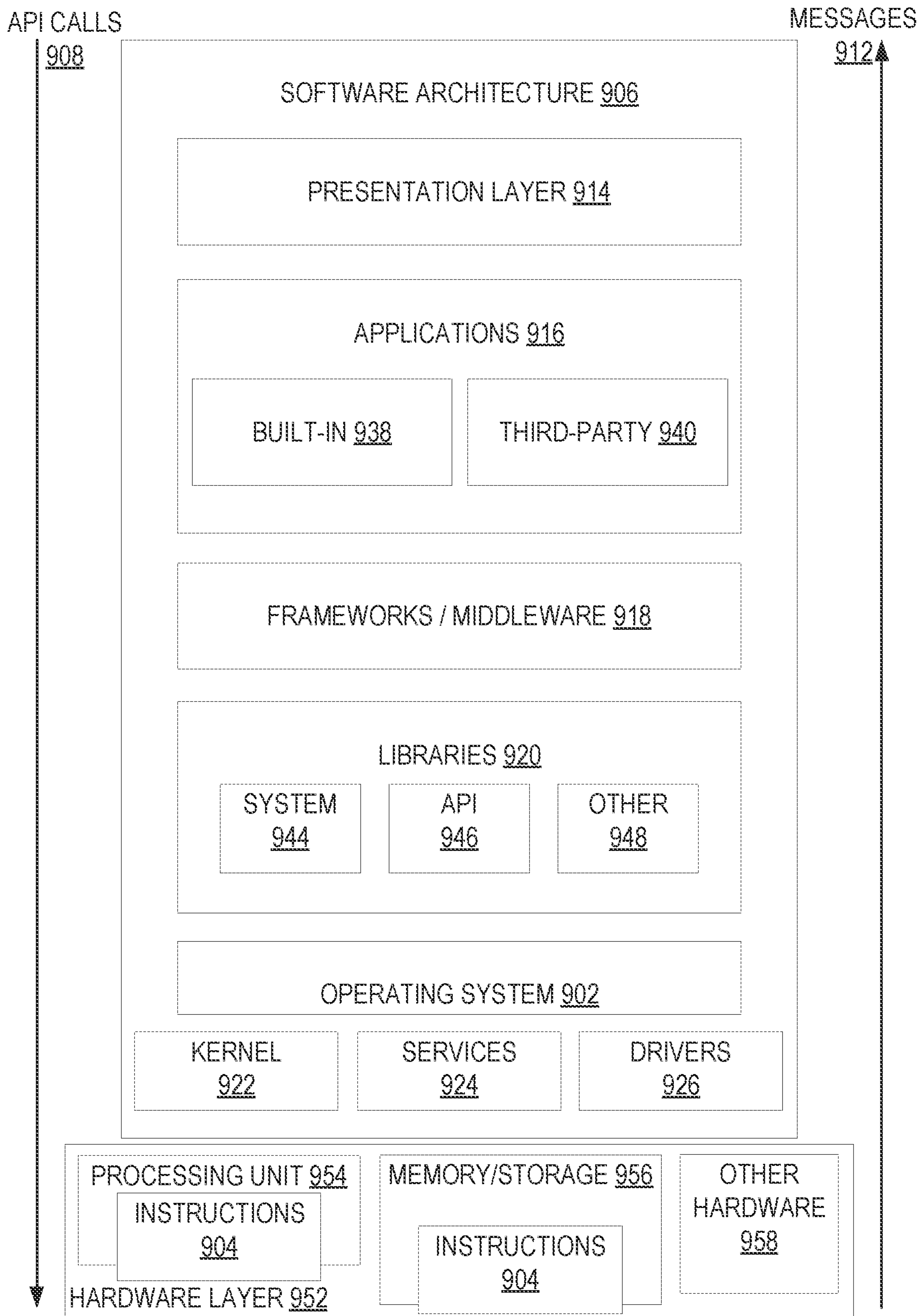


FIG. 9

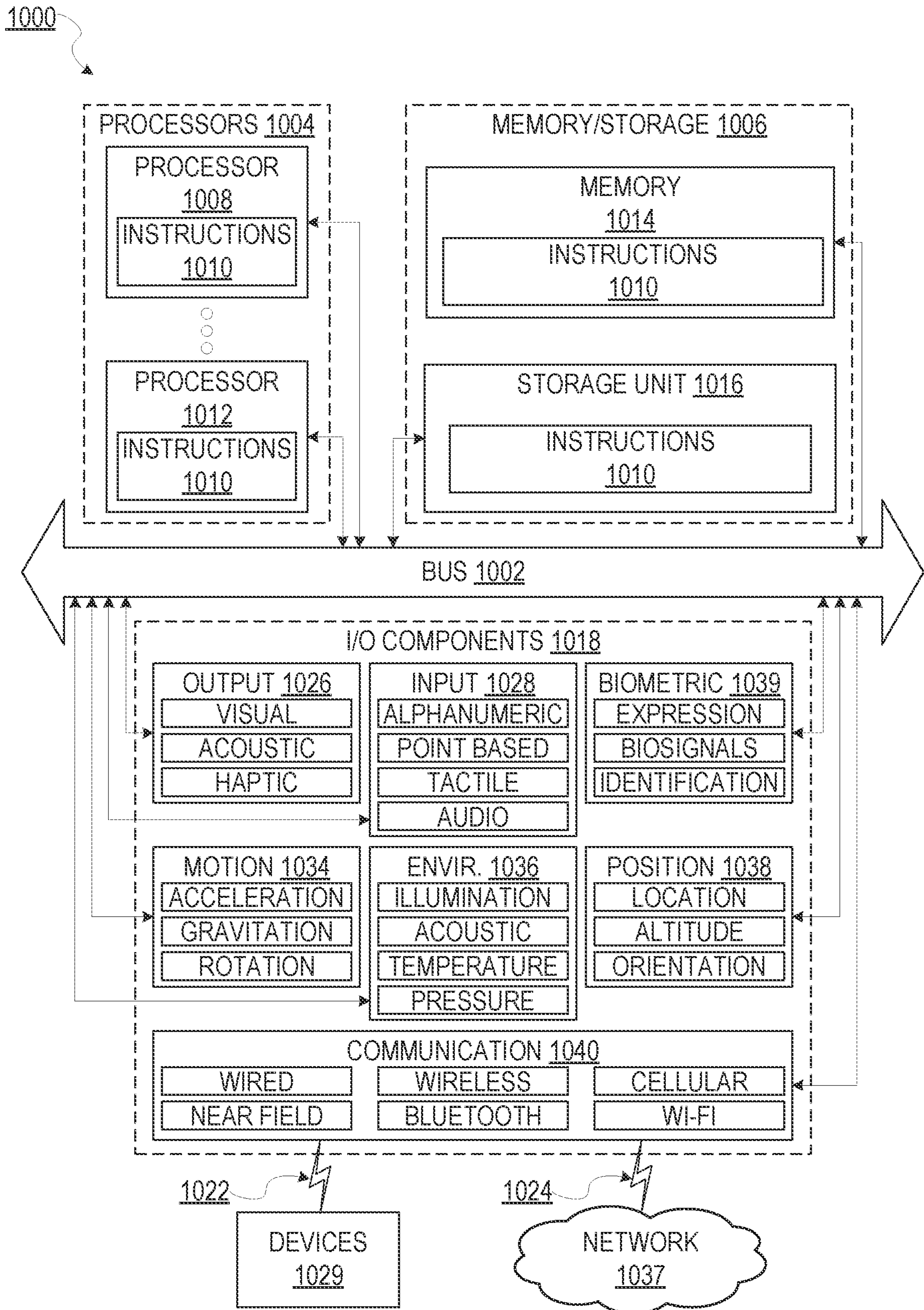


FIG. 10

SKELETAL TRACKING USING PREVIOUS FRAMES

CLAIM OF PRIORITY

This application is a continuation of U.S. patent application Ser. No. 16/710,980, filed on Dec. 11, 2019, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present disclosure relates generally to generating virtual objects based on an image depicting a user.

BACKGROUND

Virtual rendering systems can be used to create engaging and entertaining augmented reality experiences, in which virtual object graphics, such as avatars, appear to be present in the real world. Such systems can be subject to presentation problems due to environmental conditions, user actions, unanticipated visual interruption between a camera and the object being rendered, and the like. This can cause a virtual object to disappear or otherwise behave erratically, which breaks the illusion of the virtual objects being present in the real world.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, which are not necessarily drawn to scale, like numerals may describe similar components in different views. To easily identify the discussion of any particular element or act, the most significant digit or digits in a reference number refer to the figure number in which that element is first introduced. Some embodiments are illustrated by way of example, and not limitation, in the figures of the accompanying drawings in which:

FIG. 1 is a block diagram showing an example messaging system for exchanging data (e.g., messages and associated content) over a network, according to example embodiments.

FIG. 2 is a schematic diagram illustrating data which may be stored in the database of a messaging server system, according to example embodiments.

FIG. 3 is a schematic diagram illustrating a structure of a message generated by a messaging client application for communication, according to example embodiments.

FIG. 4 is a block diagram showing an example body pose estimation system, according to example embodiments.

FIG. 5 is a diagram showing body joint positions used to determine a body pose, according to example embodiments.

FIG. 6 is a flowchart illustrating example operations of the body pose estimation system, according to example embodiments.

FIGS. 7A-8C are illustrative inputs and outputs of the body pose estimation system, according to example embodiments.

FIG. 9 is a block diagram illustrating a representative software architecture, which may be used in conjunction with various hardware architectures herein described, according to example embodiments.

FIG. 10 is a block diagram illustrating components of a machine able to read instructions from a machine-readable medium (e.g., a machine-readable storage medium) and perform any one or more of the methodologies discussed herein, according to example embodiments.

DETAILED DESCRIPTION

The description that follows includes systems, methods, techniques, instruction sequences, and computing machine program products that embody illustrative embodiments of the disclosure. In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide an understanding of various embodiments. It will be evident, however, to those skilled in the art, that embodiments may be practiced without these specific details. In general, well-known instruction instances, protocols, structures, and techniques are not necessarily shown in detail.

Typically, virtual reality (VR) and augmented reality (AR) systems display avatars representing a given user by capturing an image of the user and, in addition, obtaining a depth map using a depth sensor of the real-world human body depicted in the image. By processing the depth map and the image together, the VR and AR systems can mimic actions performed by the user. While such systems work well for presenting avatars of a user, the need for a depth sensor limits the scope of their applications. This is because adding depth sensors to user devices for the purpose of displaying avatars increases the overall cost and complexity of the devices, making them less attractive.

Also, while certain systems use real-time skeletal tracking trackers to identify actions performed by a user, such trackers are noisy and require temporal filtering to be applied. This reduces their overall efficiency and consumes too many resources to apply them on mobile devices. Filtering based on classical computer vision and signal analysis can improve results slightly but not enough.

The disclosed embodiments improve the efficiency of using the electronic device by applying a first machine learning technique to identify skeletal joints of a user's body from a single image of the user and then filter or improve the identified skeletal joints by applying a second machine learning technique to previously received video frames of the user and current frame image features to predict skeletal joint positions for a current frame, such as the single image. Specifically, a video depicting a user's body is received. A current frame of the video is processed by a first machine learning technique to identify skeletal joint positions. A set of previous frames, such as 1-2 seconds of video preceding the current frame, is processed by a second machine learning technique to predict skeletal joint positions for a subsequent frame, such as the current frame. A comparison is made between the skeletal joint positions identified for the current frame by the first machine learning technique and the skeletal joint positions predicted by the second machine learning technique based on the previous frames. Any deviation or difference between the skeletal joint positions is then corrected by the second machine learning technique to improve and filter the skeletal joint positions identified for the current frame by the first machine learning technique.

The skeletal joints can then be used to modify presentation of one or more virtual objects, such as to mimic a pose corresponding to the skeletal joints. The virtual object (e.g., a three-dimensional object, such as a 3D caption, emoji, character, avatar, animation, looping animation of a personalized avatar or character, looping or non-looping animated graphic such as a dancing hot dog, a stylized word with animation, and so forth) is generated directly from a single red, green, and blue (RGB) image (e.g., a monocular RGB image) or a video of RGB images depicting the real-world user's body. The disclosed embodiments generate the virtual object without also obtaining a depth map of the real-world

user's body. This enables a user device with a simple RGB camera (without a depth sensor) to accurately and quickly render an animated virtual object based on the real-world user's body pose within the VR or AR application, allowing the user to interact with the VR or AR content in a more realistic environment.

In some embodiments, one such virtual object is selected by a user and added to the RGB image, and a pose of the virtual object is modified to match the pose of the user's body to provide the illusion that the selected virtual object is part of the real-world scene and is mimicking the user. Specifically, the disclosed embodiments process the image depicting the user's body, using machine learning techniques, to identify skeletal joints. A pose represented by the identified skeletal joints is determined. Once the pose represented by the skeletal joints is determined, corresponding skeletal joints of an avatar rig are adjusted to change a pose of the avatar to match the pose represented by the identified skeletal joints of the body of the user. The avatar with the modified pose that matches the pose represented by the identified skeletal joints of the body of the user is generated for display to the user.

FIG. 1 is a block diagram showing an example messaging system 100 for exchanging data (e.g., messages and associated content) over a network 106. The messaging system 100 includes multiple client devices 102, each of which hosts a number of applications, including a messaging client application 104 and a AR/VR application 105. Each messaging client application 104 is communicatively coupled to other instances of the messaging client application 104, the AR/VR application 105, and a messaging server system 108 via a network 106 (e.g., the Internet).

Accordingly, each messaging client application 104 and AR/VR application 105 is able to communicate and exchange data with another messaging client application 104 and AR/VR application 105 and with the messaging server system 108 via the network 106. The data exchanged between messaging client applications 104, AR/VR applications 105, and between a messaging client application 104 and the messaging server system 108 includes functions (e.g., commands to invoke functions) as well as payload data (e.g., text, audio, video, or other multimedia data).

AR/VR application 105 is an application that includes a set of functions that allow the client device 102 to access body pose estimation system 124. In some implementations, the AR/VR application 105 is a component or a feature that is part of the messaging client application 104. AR/VR application 105 uses an RGB camera to capture a monocular image of a user's real-world body. The AR/VR application 105 applies various trained machine learning techniques on the captured image of the body and one or more previous frames depicting the body to generate an avatar. For example, the avatar is generated to have a pose that is the same as a pose of the user's body depicted in the image. As another example, the avatar is generated for simultaneous display with the user, and a position of the avatar changes from one frame to another based on a relative position of the user in the image. For example, the avatar position changes to maintain a constant distance between the avatar and the user so it appears the avatar follows the user around. In some implementations, the AR/VR application 105 continuously captures images of the user's body in real time or periodically to continuously or periodically update the generated avatar. This allows the user to move around in the real world and see the avatar update in real time. The AR/VR application 105 presents various content (e.g., messages, games, advertisements, and so forth) and allows the user to modify

a pose of the avatar in the AR/VR application 105 to interact with other virtual content (e.g., the avatar pose can be modified to pick a virtual apple off of a virtual tree). Once the avatar is generated, the user can perform an action or gesture to capture an image of the user and the avatar for transmission to another user.

In order for AR/VR application 105 to generate the avatar directly from a captured RGB image, the AR/VR application 105 obtains a first trained machine learning techniques from the body pose estimation system 124 and/or messaging server system 108. The first trained machine learning technique processes the captured RGB image to extract one or more features from the RGB image that correspond to the body depicted in the captured RGB image. The features are analyzed to identify one or more skeletal joints and their respective alignment relative to one another. Specifically, the features are analyzed to determine the joint positions of a specified set of skeletal joints. The AR/VR application 105 also obtains a second trained machine learning technique from the body pose estimation system 124 and/or messaging server system 108. The second trained machine learning technique processes one or more previously captured frames (e.g., 1-2 seconds of video frames that immediately precede the RGB image) to estimate or predict skeletal joint positions for a subsequent frame. A threshold number of seconds of video frames (which may be user defined, previously specified, and/or dynamically determined) may continuously or periodically be stored in a buffer, such that the threshold number of seconds worth of video frames that precedes a current RGB image can be accessed by the second trained machine learning technique. The output or prediction of the skeletal joint positions of the second trained machine learning technique is used to filter or improve the skeletal joint positions identified by the first trained machine learning technique. In some cases, the second trained machine learning technique processes the skeletal joint positions identified by the first trained machine learning technique together with the previously captured frames to filter or improve the estimated skeletal joint positions.

The joint positions are provided to a database with an offset to identify a pose that is within the offset of the determined joint positions. After the pose is identified, an avatar is retrieved and a skeletal rig of the avatar is adjusted to mimic or copy the identified pose. In some embodiments, the skeletal rig of the avatar is adjusted directly from the joint positions that are determined rather than from an identified pose. The avatar is then generated for display based on the adjusted skeletal rig to mimic the pose of the body depicted in the captured image.

In some embodiments, the RGB image is a first frame of a plurality of frames of a video. In such cases, after a user's body is detected in the first frame using the first and second machine learning techniques, the body pose estimation system 124 estimates where the user's body will be and at what scale in a second frame of the plurality of frames. The second frame may be adjacent to the first frame. In some implementations, a third machine learning technique is applied to the first frame to predict or estimate the position and scale of the user's body in the second frame.

In training, the body pose estimation system 124 obtains a first plurality of input training images that include different real-world body poses. These training images also provide the ground truth information about the body pose depicted in each image. A first machine learning technique (e.g., a deep neural network) is trained based on features of the plurality of training images. Specifically, the first machine learning

technique extracts one or more features from a given training image and estimates a body pose by analyzing joint positions of the body depicted in the given training image. The first machine learning technique obtains the ground truth information corresponding to the training image and adjusts or updates one or more coefficients to improve subsequent estimations of a body pose depicted in a subsequent image.

In training, the body pose estimation system **124** obtains a first plurality of input training videos (each having a number of frames corresponding to a threshold video duration, such as 1-2 seconds) that include different real-world body poses. These training videos also provide the ground truth information with skeletal joint positions of the body for a subsequent frame relative to each video. Namely, a first training video may be associated with ground truth information identifying skeletal joint positions of a body depicted in the first training video in a frame immediately subsequent to the last frame in the first training video. A second machine learning technique (e.g., a neural network) is trained based on features of the plurality of training videos. Specifically, the second machine learning technique extracts one or more features from a given training video and estimates or predicts skeletal joint positions in a subsequent frame relative to a last frame of the training video by analyzing joint positions of the body depicted in the given training video. The second machine learning technique obtains the ground truth information corresponding to the training video and adjusts or updates one or more coefficients to improve subsequent estimations of a body pose depicted in a subsequent video.

In some implementations, a third machine learning technique (e.g., a deep neural network) extracts one or more features from a given training image and estimates a body pose in a subsequent image that is adjacent to the given training image by analyzing joint positions of the body depicted in the given training image. The third machine learning technique obtains the ground truth information corresponding to the training image that identifies the body pose in the subsequent image and adjusts one or more coefficients to improve subsequent estimations of a body pose depicted in a subsequent image and estimations of body pose and scale in subsequent images. In some implementations, during training, the third machine learning technique obtains reference 3D depth maps for each training image and uses the reference 3D depth map to estimate the body pose.

The messaging server system **108** provides server-side functionality via the network **106** to a particular messaging client application **104**. While certain functions of the messaging system **100** are described herein as being performed by either a messaging client application **104** or by the messaging server system **108**, it will be appreciated that the location of certain functionality either within the messaging client application **104** or the messaging server system **108** is a design choice. For example, it may be technically preferable to initially deploy certain technology and functionality within the messaging server system **108**, but to later migrate this technology and functionality to the messaging client application **104** where a client device **102** has a sufficient processing capacity.

The messaging server system **108** supports various services and operations that are provided to the messaging client application **104**. Such operations include transmitting data to, receiving data from, and processing data generated by the messaging client application **104**. This data may include message content, client device information, geolocation information, media annotation and overlays, virtual

objects, message content persistence conditions, social network information, and live event information, as examples. Data exchanges within the messaging system **100** are invoked and controlled through functions available via user interfaces (UIs) of the messaging client application **104**.

Turning now specifically to the messaging server system **108**, an Application Program Interface (API) server **110** is coupled to, and provides a programmatic interface to, an application server **112**. The application server **112** is communicatively coupled to a database server **118**, which facilitates access to a database **120** in which is stored data associated with messages processed by the application server **112**.

Dealing specifically with the API server **110**, this server **110** receives and transmits message data (e.g., commands and message payloads) between the client device **102** and the application server **112**. Specifically, the API server **110** provides a set of interfaces (e.g., routines and protocols) that can be called or queried by the messaging client application **104** in order to invoke functionality of the application server **112**. The API server **110** exposes various functions supported by the application server **112**, including account registration; login functionality; the sending of messages, via the application server **112**, from a particular messaging client application **104** to another messaging client application **104**; the sending of media files (e.g., images or video) from a messaging client application **104** to the messaging server application **114**, and for possible access by another messaging client application **104**; the setting of a collection of media data (e.g., story); the retrieval of such collections; the retrieval of a list of friends of a user of a client device **102**; the retrieval of messages and content; the adding and deleting of friends to a social graph; the location of friends within a social graph; access to user conversation data; access to avatar information stored on messaging server system **108**; and opening an application event (e.g., relating to the messaging client application **104**).

The application server **112** hosts a number of applications and subsystems, including a messaging server application **114**, an image processing system **116**, a social network system **122**, and the body pose estimation system **124**. The messaging server application **114** implements a number of message processing technologies and functions, particularly related to the aggregation and other processing of content (e.g., textual and multimedia content) included in messages received from multiple instances of the messaging client application **104**. As will be described in further detail, the text and media content from multiple sources may be aggregated into collections of content (e.g., called stories or galleries). These collections are then made available, by the messaging server application **114**, to the messaging client application **104**. Other processor- and memory-intensive processing of data may also be performed server-side by the messaging server application **114**, in view of the hardware requirements for such processing.

The application server **112** also includes an image processing system **116** that is dedicated to performing various image processing operations, typically with respect to images or video received within the payload of a message at the messaging server application **114**. A portion of the image processing system **116** may also be implemented by the body pose estimation system **124**.

The social network system **122** supports various social networking functions and services and makes these functions and services available to the messaging server application **114**. To this end, the social network system **122** maintains and accesses an entity graph within the database

120. Examples of functions and services supported by the social network system **122** include the identification of other users of the messaging system **100** with which a particular user has relationships or is “following” and also the identification of other entities and interests of a particular user. Such other users may be referred to as the user’s friends.

The application server **112** is communicatively coupled to a database server **118**, which facilitates access to a database **120** in which is stored data associated with messages processed by the messaging server application **114**.

FIG. **2** is a schematic diagram **200** illustrating data, which may be stored in the database **120** of the messaging server system **108**, according to certain example embodiments. While the content of the database **120** is shown to comprise a number of tables, it will be appreciated that the data could be stored in other types of data structures (e.g., as an object-oriented database).

The database **120** includes message data stored within a message table **214**. An entity table **202** stores entity data, including an entity graph **204**. Entities for which records are maintained within the entity table **202** may include individuals, corporate entities, organizations, objects, places, events, and so forth. Regardless of type, any entity regarding which the messaging server system **108** stores data may be a recognized entity. Each entity is provided with a unique identifier, as well as an entity type identifier (not shown).

The entity graph **204** furthermore stores information regarding relationships and associations between entities. Such relationships may be social, professional (e.g., work at a common corporation or organization), interest-based, or activity-based, merely for example.

Message table **214** may store a collection of conversations between a user and one or more friends or entities. Message table **214** may include various attributes of each conversation, such as the list of participants, the size of the conversation (e.g., number of users and/or number of messages), the chat color of the conversation, a unique identifier for the conversation, and any other conversation related feature(s).

The database **120** also stores annotation data, in the example form of filters, in an annotation table **212**. Database **120** also stores annotated content received in the annotation table **212**. Filters for which data is stored within the annotation table **212** are associated with and applied to videos (for which data is stored in a video table **210**) and/or images (for which data is stored in an image table **208**). Filters, in one example, are overlays that are displayed as overlaid on an image or video during presentation to a recipient user. Filters may be of various types, including user-selected filters from a gallery of filters presented to a sending user by the messaging client application **104** when the sending user is composing a message. Other types of filters include geolocation filters (also known as geo-filters), which may be presented to a sending user based on geographic location. For example, geolocation filters specific to a neighborhood or special location may be presented within a UI by the messaging client application **104**, based on geolocation information determined by a Global Positioning System (GPS) unit of the client device **102**. Another type of filter is a data filter, which may be selectively presented to a sending user by the messaging client application **104**, based on other inputs or information gathered by the client device **102** during the message creation process. Examples of data filters include current temperature at a specific location, a current speed at which a sending user is traveling, battery life for a client device **102**, or the current time.

Other annotation data that may be stored within the image table **208** may be a real-time special effect and sound that may be added to an image or a video.

As mentioned above, the video table **210** stores video data which, in one embodiment, is associated with messages for which records are maintained within the message table **214**. Similarly, the image table **208** stores image data associated with messages for which message data is stored in the entity table **202**. The entity table **202** may associate various annotations from the annotation table **212** with various images and videos stored in the image table **208** and the video table **210**.

Trained machine learning technique(s) **207** stores parameters that have been trained during training of the body pose estimation system **124**. For example, trained machine learning techniques **207** stores the trained parameters of one or more neural network machine learning techniques.

Body pose training images **209** stores a plurality of images of depictions of real-world body poses. The plurality of images stored in the body pose training images **209** includes various depictions of a real-world body pose together with 3D depth information captured from a 3D depth sensor for each image. The plurality of images also include ground truth information identifying the body pose and the ground truth skeletal joint positions of one or more body skeletal joints. Examples of the skeletal joint positions that are identified for a given pose are shown in FIG. **5**. These skeletal joint positions include a position of the right wrist, right elbow, right shoulder, a nose on a face, a left shoulder, a left elbow, and a left wrist. The skeletal joint positions can be determined relative to one another (e.g., how high one skeletal joint is relative to another or how high or low one skeletal joint is relative to the nose) to determine a given pose. These body pose training images **209** are used by the body pose estimation system **124** to train the first machine learning technique used to determine a body pose and skeletal joint positions from a received RGB monocular image of a user’s body.

Body pose training images **209** stores a plurality of videos (1-2 second video segments) of depictions of real-world body poses. The plurality of videos stored in the body pose training images **209** includes various depictions of real-world body poses. The plurality of videos also include ground truth information identifying the ground truth skeletal joint positions of a body depicted in a subsequent frame relative to a last frame in each of the plurality of videos. These body pose training images **209** are used by the body pose estimation system **124** to train the second machine learning technique used to predicts skeletal joint positions for a subsequent frame from a received RGB monocular video of a user’s body.

Returning to FIG. **2**, a story table **206** stores data regarding collections of messages and associated image, video, or audio data, which are compiled into a collection (e.g., a story or a gallery). The creation of a particular collection may be initiated by a particular user (e.g., each user for which a record is maintained in the entity table **202**). A user may create a “personal story” in the form of a collection of content that has been created and sent/broadcast by that user. To this end, the UI of the messaging client application **104** may include an icon that is user-selectable to enable a sending user to add specific content to his or her personal story.

A collection may also constitute a “live story,” which is a collection of content from multiple users that is created manually, automatically, or using a combination of manual and automatic techniques. For example, a “live story” may

constitute a curated stream of user-submitted content from various locations and events. Users whose client devices have location services enabled and are at a common location event at a particular time may, for example, be presented with an option, via a UI of the messaging client application 5 **104**, to contribute content to a particular live story. The live story may be identified to the user by the messaging client application **104** based on his or her location. The end result is a “live story” told from a community perspective.

A further type of content collection is known as a “location story,” which enables a user whose client device **102** is located within a specific geographic location (e.g., on a college or university campus) to contribute to a particular collection. In some embodiments, a contribution to a location story may require a second degree of authentication to 10 verify that the end user belongs to a specific organization or other entity (e.g., is a student on the university campus).

FIG. 3 is a schematic diagram illustrating a structure of a message **300**, according to some embodiments, generated by a messaging client application **104** for communication to a further messaging client application **104** or the messaging server application **114**. The content of a particular message **300** is used to populate the message table **214** stored within the database **120**, accessible by the messaging server application **114**. Similarly, the content of a message **300** is stored 20 in memory as “in-transit” or “in-flight” data of the client device **102** or the application server **112**. The message **300** is shown to include the following components:

A message identifier **302**: a unique identifier that identifies the message **300**.

A message text payload **304**: text, to be generated by a user via a UI of the client device **102** and that is included in the message **300**.

A message image payload **306**: image data, captured by a camera component of a client device **102** or retrieved from memory of a client device **102**, and that is included in the message **300**.

A message video payload **308**: video data, captured by a camera component or retrieved from a memory component of the client device **102** and that is included in the message **300**.

A message audio payload **310**: audio data, captured by a microphone or retrieved from the memory component of the client device **102**, and that is included in the message **300**.

Message annotations **312**: annotation data (e.g., filters, stickers, or other enhancements) that represents annotations to be applied to message image payload **306**, message video payload **308**, or message audio payload **310** of the message **300**.

A message duration parameter **314**: parameter value indicating, in seconds, the amount of time for which content of the message (e.g., the message image payload **306**, message video payload **308**, message audio payload **310**) is to be presented or made accessible to a user via the messaging client application **104**.

A message geolocation parameter **316**: geolocation data (e.g., latitudinal and longitudinal coordinates) associated with the content payload of the message. Multiple message geolocation parameter **316** values may be included in the payload, with each of these parameter values being associated with respect to content items included in the content (e.g., a specific image within the message image payload **306**, or a specific video in the message video payload **308**).

A message story identifier **318**: identifier value identifying one or more content collections (e.g., “stories”) with

which a particular content item in the message image payload **306** of the message **300** is associated. For example, multiple images within the message image payload **306** may each be associated with multiple content collections using identifier values.

A message tag **320**: each message **300** may be tagged with multiple tags, each of which is indicative of the subject matter of content included in the message payload. For example, where a particular image included in the message image payload **306** depicts an animal (e.g., a lion), a tag value may be included within the message tag **320** that is indicative of the relevant animal. Tag values may be generated manually, based on user input, or may be automatically generated using, for example, image recognition.

A message sender identifier **322**: an identifier (e.g., a messaging system identifier, email address, or device identifier) indicative of a user of the client device **102** on which the message **300** was generated and from which the message **300** was sent.

A message receiver identifier **324**: an identifier (e.g., a messaging system identifier, email address, or device identifier) indicative of user(s) of the client device **102** to which the message **300** is addressed. In the case of a conversation between multiple users, the identifier may indicate each user involved in the conversation.

The contents (e.g., values) of the various components of message **300** may be pointers to locations in tables within which content data values are stored. For example, an image value in the message image payload **306** may be a pointer to (or address of) a location within an image table **208**. Similarly, values within the message video payload **308** may point to data stored within a video table **210**, values stored within the message annotations **312** may point to data stored in an annotation table **212**, values stored within the message story identifier **318** may point to data stored in a story table **206**, and values stored within the message sender identifier **322** and the message receiver identifier **324** may point to user records stored within an entity table **202**.

FIG. 4 is a block diagram showing an example body pose estimation system **124**, according to example embodiments. Body pose estimation system **124** operates on a set of input data (e.g., a monocular image **401** depicting a real body of a user, body pose training image data **402**, monocular video depicting a body of a user **403**, and body pose training video data **404**). The set of input data is obtained from body pose training images **209** stored in database(s) **200** during the training phases and is obtained from an RGB camera of a client device **102** when an AR/VR application **105** is being used. Body pose estimation system **124** includes a first machine learning technique module **412**, a skeletal joint position module **414**, a second machine learning technique module **417**, a pose determination module **416**, a virtual object modification module **418**, a virtual object mode selection module **419** and a virtual object display module **420**.

During training, according to the disclosed embodiments, body pose estimation system **124** receives a given training image (e.g., monocular image **401** depicting a real-world body, such as an image of a user’s face, arms, torso, hips and legs) from body pose training image data **402**. The body pose estimation system **124** applies one or more machine learning techniques using the first machine learning technique module **412** on the given training image. The first machine learning technique module **412** extracts one or more features from the given training image to estimate skeletal joint positions of the skeletal joints depicted in the

image. For example, the first machine learning technique module **412** obtains the given training image depicting a user's face, arms, torso, hips and legs. The first machine learning technique module **412** extracts features from the image that correspond to the user's face and arms to identify one or more skeletal joints (e.g., the joints shown in FIG. 5 including the left/right wrist joints, left/right elbow joints, left/right shoulder joints, and a nose position).

The first machine learning technique module **412** determines the relative positions of the identified skeletal joints to determine a pose that corresponds to the skeletal joint positions. In an embodiment, the first machine learning technique module **412** uses depth information associated with the given training image to assist in the determination of the skeletal joint positions and pose of the body. The first machine learning technique module **412** compares the determined skeletal joint positions and the determined pose with the ground truth skeletal joint positions and pose provided as part of the body pose training image data **402**. Based on a difference threshold of the comparison, the first machine learning technique module **412** updates one or more coefficients and obtains one or more additional body pose training images. After a specified number of epochs or batches of training images have been processed and/or when the difference threshold reaches a specified value, the first machine learning technique module **412** completes training and the parameters and coefficients of the first machine learning technique module **412** are stored in the trained machine learning technique(s) **207**. In some embodiments, portions of the first machine learning technique module **412** are implemented by skeletal joint position module **414** and pose determination module **416**.

During training, according to the disclosed embodiments, body pose estimation system **124** receives a given training video (e.g., monocular video depicting a body of user **403** depicting a real-world body, such as an image of a user's face, arms, torso, hips and legs) from body pose training image data **402**. The body pose estimation system **124** applies one or more machine learning techniques using the second machine learning technique module **417** on the given training video. The second machine learning technique module **417** extracts one or more features from the given training video to predict skeletal joint positions for a frame subsequent to the last frame of the video. For example, the second machine learning technique module **417** obtains the given training video depicting movement of a user's face, arms, torso, hips and legs across a set of frames in 1-2 seconds of video. The second machine learning technique module **417** extracts features from the video that correspond to the user's face and arms to predict one or more skeletal joints in a frame that is subsequent to the last frame of the video (e.g., the joints shown in FIG. 5 including the left/right wrist joints, left/right elbow joints, left/right shoulder joints, and a nose position). In some cases, the frame subsequent to the last frame of the video may not be available and not received by the second machine learning technique module **417** but the second machine learning technique module **417** predicts skeletal joint positions for the subsequent frame from the previous frames.

The second machine learning technique module **417** predicts skeletal joint positions for one or more subsequent frames that follow the given training video. For example, the second machine learning technique module **417** may process frames 2-25 of a given video and frame 26 of the same video to predict skeletal joint positions of a body depicted in frame 26 of the same video. The second machine learning technique module **417** compares the determined/predicted skeletal joint positions with the ground truth skeletal joint positions provided as part of the body pose training image data **402**. The ground truth skeletal joint positions may provide the ground truth real skeletal joint positions for the subsequent frame 26 for movement of a body depicted in frames 2-25. Based on a difference threshold of the comparison, the second machine learning technique module **417** updates one or more coefficients and obtains one or more additional body pose training videos. After a specified number of epochs or batches of training videos have been processed and/or when the difference threshold reaches a specified value, the second machine learning technique module **417** completes training and the parameters and coefficients of the second machine learning technique module **417** are stored in the trained machine learning technique(s) **207**. In some embodiments, portions of the second machine learning technique module **417** are implemented by skeletal joint position module **414** and pose determination module **416**.

In an example, the second machine learning technique module **417** is trained to recognize movement of skeletal joint positions across a set of consecutive frames. The second machine learning technique module **417** can receive a current video frame and/or skeletal joint positions determined from that current video frame. The second machine learning technique module **417** can process a set of previous frames that depict movement of the body together with image features of a current frame and predict estimated skeletal joint positions for a next frame. Based on the prediction, the second machine learning technique module **417** compares the predicted estimated skeletal joint positions with the skeletal joint positions determined for the current frame by the first machine learning technique module **412**. The second machine learning technique module **417** can then determine any deviation and correction needed based on the comparison.

Specifically, the second machine learning technique module **417** receives a collection of skeletal joint positions that have been determined for a current frame (e.g., from the first machine learning technique module **412**). The collection of skeletal joint positions may indicate that the left wrist is at a particular coordinate in two-dimensional (2D) or three-dimensional (3D) space (4, 6) and that the right wrist is at another particular coordinate in the 2D or 3D space (10, 8). The second machine learning technique module **417** processes a sequence of video frames that immediately precede the current frame by 1-2 seconds and image features of a current frame. The second machine learning technique module **417** analyzes movement of the skeletal joints across the sequence of the video frames to predict estimated positions of the skeletal joints in the current frame or for a frame that is subsequent to the current frame. As an example, the second machine learning technique module **417** predicts the coordinates of left wrist to be (4, 7) and the right wrist to be (10, 8). The second machine learning technique module **417** compares the predicted coordinates with the coordinates determined for the current frame (e.g., by the first machine learning technique module **412**). The second machine learning technique module **417** may filter or correct at least some of the coordinates that do not match. In this example, the second machine learning technique module **417** determines that the left wrist coordinates (4, 6) do not match the coordinates predicted based on the previous video frames (4, 7) and, as such, corrects the skeletal joint positions to be (4, 7) in the collection of skeletal joint positions.

After training, according to the disclosed embodiments, body pose estimation system **124** receives an input image

401 (e.g., monocular image depicting a real-world body, such as an image of a user's face, arms, torso, hips and legs) as a single RGB image from a client device 102. The body pose estimation system 124 applies the first trained machine learning technique module 412 to the received input image 5 401 to extract one or more features representing the skeletal joints of the body depicted in the image 401. The body pose estimation system 124 applies the second trained machine learning technique module 417 to the received monocular video depicting a body of a user 403 to extract one or more 10 features representing the skeletal joints of the body depicted in the monocular video depicting a body of a user 403 and to generate a prediction or estimation of skeletal joints in a subsequent frame.

In some embodiments, the rate at which the features are extracted from a video stream depicting the user's body is based on how close or far the user is positioned relative to the image capture device. For example, if the user is positioned far from the image capture device and appears really small in the images of the video, the features and as a result a pose of the user's body are analyzed less frequently (e.g., every 5 frames). If the user is positioned close to the image capture device and appears large in the images of the video, the features and as a result a pose of the user's body are analyzed more frequently (e.g., every 2 frames). The extracted features are provided to the skeletal joint position module 414. The skeletal joint position module 414 analyzes the skeletal joint features to determine coordinates of specific skeletal joints. For example, the skeletal joint position module 414 determines the x,y coordinates of a particular point of each skeletal joint, such as the x,y coordinates of the left wrist, the x,y coordinates of the left elbow, the x,y coordinates of the left shoulder, the x,y coordinates of the nose (or other facial feature such as mouth, ears or eyes), the x,y coordinates of the right wrist, the x,y coordinates of the right elbow, and the x,y coordinates of the right shoulder. The skeletal joint position module 414 provides the x,y coordinates of the specified skeletal joints to the second machine learning technique module 417. In some embodiments, the second machine learning technique module 417 provides the x,y coordinates of the filtered skeletal joints to the virtual object modification module 418. In an embodiment, the x,y coordinates represent x,y offsets of each skeletal joint relative to a neutral pose of the body.

The second machine learning technique module 417 analyzes movement of the skeletal joints across the sequence of the video frames received prior to the monocular image depicting a body of a user 401 to predict estimated positions of the skeletal joints in the monocular image depicting a body of a user 401. The number of previous video frames or duration of the previously received video segments analyzed by the second machine learning technique module 417 may be set by a user, predetermined, or dynamically adjusted. In some cases, the number of previous video frames that are analyzed may be increased (e.g., from 1 second of video to 2 seconds of video) if the amount of filtering or correction of the skeletal joint positions determined by the first machine learning technique module 412 exceeds a specified threshold. In some cases, the number of previous video frames that are analyzed may be increased (e.g., from 1 second of video to 2 seconds of video) based on a distance between a user and a camera exceeding a specified threshold. The second machine learning technique module 417 may filter or correct at least some of the coordinates of one or more skeletal joint positions provided by the skeletal joint position module 414 that do not match the skeletal joint positions predicted based on previous video frames by the

second machine learning technique module 417. In this example, the second machine learning technique module 417 determines that the left wrist coordinates (4, 6) do not match the coordinates predicted based on the previous video frames (4, 7) and, as such, corrects the skeletal joint positions to be (4, 7) in the collection of skeletal joint positions.

Pose determination module 416 determines the relative positions of each of the skeletal joints received from the second machine learning technique module 417. For example, the pose determination module 416 determines that the left wrist is lower in the y direction than the right wrist by more than a first specified amount but less than second specified amount. Based on this determination, the pose determination module 416 estimates that the pose depicted in the image corresponds to a first pose. As another example, the pose determination module 416 determines that the left wrist is lower in the y direction than the right wrist by more than the first specified amount and the second specified amount. Based on this determination, the pose determination module 416 estimates that the pose depicted in the image corresponds to a second pose. In some embodiments, the pose determination module 416 searches a database based on the x,y coordinates received from the skeletal joint position module 414 to identify a pose that is within a predetermined threshold of the x,y coordinates.

Virtual object mode selection module 419 receives from a client device 102 a selection of a virtualization mode. For example, a user of the AR/VR application 105 may be presented with a list of mode options. In response to receiving a user selection of a given mode option from the list, the given mode is provided to the virtual object mode selection module 419 as the selection of the virtualization mode. The mode options may include a single avatar mimic option, a multiple avatar mimic option, an avatar visualization control option, an avatar follow option, and an avatar virtual world interaction option. The virtualization mode selection controls the way in which the skeletal joint positions of the user's body affect the skeletal rig of the avatar or the position of the avatar in the display relative to the user. The mode options may include a list of avatars of different forms and types for a user to select. The selected avatar is then used to retrieve the corresponding rig to adjust the skeletal rig according to the user's pose.

The virtual object modification module 418 can adjust the skeletal rig of a given avatar based on the mode selected by the virtual object mode selection module 419 and the pose or skeletal joint positions received from the skeletal joint position module 414 and/or pose determination module 416. The virtual object modification module 418 adjusts the way in which the avatar is presented in an image, such as by changing the pose, a visual attribute and/or a position of the avatar in the image. The adjusted avatar is provided by the virtual object modification module 418 to the virtual object display module 420. Virtual object display module 420 combines the adjusted avatar into the received monocular image depicting the user's body so that both the adjusted avatar and the user are simultaneously presented in an image. The image is provided by the virtual object display module 420 to the client device 102 and can then be sent to another user or stored for later access and display.

For example, selection of the single avatar mimic option instructs the virtual object modification module 418 to modify the skeletal rig of the avatar based on the relative distances between the skeletal joints of the user's body. In this way, the skeletal rig is modified to copy or mimic the pose represented by the user's body. Specifically, if the left wrist is determined to be offset higher from a neutral

position of the left wrist by a certain ratio or percentage in the captured RGB image, the corresponding left wrist of the avatar skeletal rig is raised to a position that is also higher from a neutral position of the left wrist of the avatar by the same ratio or percentage. Each skeletal rig joint is similarly adjusted to copy the relative position of the skeletal joint positions of the body depicted in the image. For example, as shown in FIG. 7A, a user's body **723** is identified and the left wrist joint position of the user's body **723** is determined to be offset lower than a neutral left wrist joint position by a first amount, the right wrist joint position of the user's body **723** is determined to be offset higher than the neutral right wrist joint position by a second amount. In an embodiment, FIG. 5 represents the neutral skeletal joint positions of a user's body. The skeletal joint positions of a rig of the avatar **734** are similarly adjusted relative to their corresponding neutral positions to be offset by similar first and second amounts. As a result, the avatar **734** appears to mimic or copy the pose represented by the user's body **723**.

As another example, selection of the multiple avatar mimic option instructs the virtual object modification module **418** to modify the skeletal rigs of multiple copies of the avatar based on the relative distances between the skeletal joints of the user's body. The multiple avatar mimic option causes avatars that are depicted in a first neutral position **1020** as shown in image **1011** of FIG. 8A to animate to a pose corresponding to a user's body as shown in image **1013**. Specifically, multiple avatars shown in image **1011** may appear in different neutral poses (e.g., crawling on the floor on all four legs). In response to selection of the multiple avatar mimic option, the pose estimation system **124** analyzes a sequence of received monocular RGB images to determine when a pose of the user matches a specified pose. In response to determining that the pose of the user matches the specified pose, the pose estimation system **124** causes all of the avatars to copy the pose of the user (e.g., standing on two legs and positioning left and right arms in a similar pose as a user). The skeletal rigs of the avatars are adjusted in a similar manner as done for single avatar when the single avatar mimic option was selected. Another example is shown in images **1019** and **1015**. In image **1013**, avatars **1030** transition from a neutral position (laying flat on the floor) to a pose position **1032** that mimics the pose of the user (e.g., standing on two legs and positioning left and right arms in a similar pose as a user). When the avatar is a collection of papers, the papers are animated as flying around until the papers are arranged in a certain order in front of or behind the user and in the pose that matches the user's body pose.

As another example, selection of the avatar visualization control option instructs the virtual object modification module **418** to modify a visual attribute of the avatar based on a pose of the user. For example, an avatar is presented on a screen as moving at a given rate from top to bottom or from left to right. Specifically, clouds shown in image **1110** of FIG. 8B can be animated moving down across the screen in front of the user. Based on a pose of the user or based on how slowly or quickly a user transitions from one pose to another, the rate at which the clouds move across the screen can be increased or decreased. As another example, an avatar (e.g., clouds) can be positioned over the user's hands as shown in image **1112**. When the user changes pose from hands being vertical and straight up in the air to having the hands extending horizontally, the avatar continues to follow the user's hands and be positioned over the user's hands but a visual attribute of the avatar changes (e.g., the clouds now present a rainbow above the user from a first cloud posi-

tioned over one hand to a second cloud positioned over a second hand) as shown in image **1114**. The change in the visual attribute may also include changing a face depicted on the avatar from smiling to frowning or a color of the avatar can be changed based on the change to the user's skeletal joint positions.

As another example, selection of the avatar virtual world interaction instructs the virtual object modification module **418** to cause the avatar to interact with another virtual object that is in the image. For example, the avatar is displayed in an image that includes virtual objects (e.g., a virtual tree and a virtual apple on the tree). The avatar pose and movement track and mimic skeletal joint positions of the user in way that allows the avatar to interact with the virtual objects. Specifically, FIG. 8C shows a virtual apple **810** and an avatar **812** with arms that have the right and left wrists at a particular position level to each other in the vertical direction. The right hand of the avatar **812** in this position is at a first distance away from the virtual apple **810**. When the user's body **820** depicted in the image raises the right arm, the avatar's **812** right arm **816** is also raised relative to the left arm, which also raises the right wrist of the avatar **812**. In this position, the right wrist and elbow of the avatar **812** is higher than the left wrist and elbow, and the right hand of the avatar **812** is at a second distance away from the virtual apple **810**. The distance between the right hand of the avatar **812** and the position of the virtual apple **810** is determined to be less than a threshold, and as a result, the virtual apple **810** becomes detached from the virtual tree **814** and is pinned to the right hand of the avatar **812**. As shown, the virtual apple **810** is no longer presented on the virtual tree **814**, and when the user lowers their arms, the avatar's left and right arms are also lowered to reveal that the right hand is now holding the virtual apple **810**. In this way, the user can cause the avatar **812** to mimic the user's pose to interact with one or more virtual objects in an image or video.

As another example, selection of the avatar follow option instructs the virtual object modification module **418** to maintain a given distance between the avatar and the user. Specifically, this option causes the avatar to follow the user through a sequence of images. For example, the position of the avatar in the image depicting the user's body is changed as the user's body position in the image changes. In particular, if the user moves to the right by a certain amount, the position of the displayed avatar also is moved to the right by the same certain amount. FIG. 8C shows an avatar in a first position **830** relative to the user depicted in the image and at a first distance between the avatar and the user in 2D or 3D space. As the user moves to a second position, the avatar is moved to a second position **832** to maintain the same distance from the user depicted in the image.

FIG. 6 is a flowchart illustrating example operations of the body pose estimation system **124** in performing process **600**, according to example embodiments. The process **600** may be embodied in computer-readable instructions for execution by one or more processors such that the operations of the process **600** may be performed in part or in whole by the functional components of the messaging server system **108** and/or AR/VR application **105**; accordingly, the process **600** is described below by way of example with reference thereto. However, in other embodiments, at least some of the operations of the process **600** may be deployed on various other hardware configurations. The process **600** is therefore not intended to be limited to the messaging server system **108** and can be implemented in whole, or in part, by any other component. Some or all of the operations of process **600** can be in parallel, out of order, or entirely omitted.

At operation 601, the body pose estimation system 124 receives a monocular image that includes a depiction of a body of a user. For example, the first machine learning technique module 412 receives the monocular image 401 depicting a body of a user. The first machine learning technique module 412 extracts one or more features from the image indicating skeletal joints.

At operation 602, the body pose estimation system 124 detects a plurality of skeletal joints of the body depicted in the monocular image 401. For example, the skeletal joint position module 414 processes the features extracted by the first machine learning technique module 412 to determine positions of a set of skeletal joints. The positions may be determined with respect to neutral positions of each skeletal joint.

At operation 603, the body pose estimation system 124 accesses a video feed comprising a plurality of monocular images received prior to the monocular image. For example, pose determination module 416 accesses 1-2 seconds of video that was received prior to the current image that is processed by the first machine learning technique module 412.

At operation 604, the body pose estimation system 124 filters, using the video feed, the plurality of skeletal joints of the body detected based on the monocular image. For example, the second machine learning technique module 417 predicts skeletal joint positions for a current frame based on skeletal joint positions in one or more previous frames (e.g., based on movement of the body in the previous 1-2 seconds of video). The second machine learning technique module 417 filters or corrects any mismatches between the skeletal joint positions output by the first machine learning technique module 412 based on the actually received current video frame and the predicted skeletal joint positions output by the second machine learning technique module 417 based on the previous video frames and/or image features of the current frame.

At operation 605, the body pose estimation system 124 determines a pose represented by the body depicted in the monocular image based on the filtered plurality of skeletal joints of the body.

FIGS. 7A-C show illustrative inputs and outputs of the body pose estimation system 124, according to example embodiments. The inputs and outputs shown in FIGS. 7A-C can be implemented by the AR/VR application 105. In some embodiments, a first user accesses the body pose estimation system 124 to exchange images depicting the user and a corresponding avatar to another user. The first user is presented with a screen 711 that includes an avatar selection region and an option to start exchanging images. After the first user selects the avatar and selects the start option, an instruction is presented to the first user in screen 712 to position the first user a specified distance from the image capture device. For example, the first user is instructed to step back so that the user's body fits within the image captured by the image capture device.

In an embodiment, as shown in the screen 712, the first user is instructed to step far enough away from the image capture device until a predetermined set of skeletal joints are visible but not all of the skeletal joints are visible. Specifically, the body pose estimation system 124 may only need the wrist positions, elbow positions, shoulder positions and nose position to be visible in an image, but not the leg positions. In some embodiments, the skeletal joints of the first user that are visible in the image cause the same corresponding skeletal joints of the avatar to be adjusted. For example, if only the first user's arms are visible in the image,

then only the avatar's arms are adjusted to mimic the first user's arm position. If the user's entire body is visible including the user's legs, then the entire avatar rig is adjusted including the avatar legs to mimic the first user's body pose.

The user's body pose is obtained in screen 713 and the body pose estimation system 124 generates for display in screen 714 an avatar 734 with the same or similar pose as the first user. The first user can speak a predetermined word or, if the user maintains the same pose for a threshold period of time, a screenshot or image is captured that features the user in the pose and the avatar mimicking the user's pose.

As shown in FIG. 7B, a screenshot 741 is shown to the first user in screen 721. A blank space 760 may be included in screen 721 indicating that receipt of a corresponding screenshot from a second user is pending. The first user may select or press on the blank space 760 to cause a list of recipients to be presented in screen 722. Specifically, screen 722 presents a list of the first user's friends. The first user may select a given friend "Matt" and the body pose estimation system 124 transmits the screenshot 741 to the selected friend "Matt".

As shown in FIG. 7C, the second user 731 follows a similar sequence as the first user to cause a second avatar 732 to mimic a pose of the second user 731 as shown in screen 730. Particularly, screen 730 is provided on a different mobile device that is associated with the second user 731. The second user 731 selects the second avatar 732 and is instructed to step back so that the body pose estimation system 124 can estimate the body pose of the user 731 and adjust the selected second avatar 732 to mimic the second user's body pose. The body pose estimation system 124 captures an image 751 depicting the second user 731 and the second avatar 732 in the given pose and presents the captured image 751 in a screen 740. The captured image 751 is automatically sent to the first user. The captured image 751 depicting the second user 731 and the second avatar 732 in a given pose is presented together with the screenshot 741 depicting the first user and the first avatar in another pose.

FIG. 9 is a block diagram illustrating an example software architecture 906, which may be used in conjunction with various hardware architectures herein described. FIG. 9 is a non-limiting example of a software architecture and it will be appreciated that many other architectures may be implemented to facilitate the functionality described herein. The software architecture 906 may execute on hardware such as machine 1000 of FIG. 10 that includes, among other things, processors 1004, memory 1014, and input/output (I/O) components 1018. A representative hardware layer 952 is illustrated and can represent, for example, the machine 1000 of FIG. 10. The representative hardware layer 952 includes a processing unit 954 having associated executable instructions 904. Executable instructions 904 represent the executable instructions of the software architecture 906, including implementation of the methods, components, and so forth described herein. The hardware layer 952 also includes memory and/or storage modules memory/storage 956, which also have executable instructions 904. The hardware layer 952 may also comprise other hardware 958.

In the example architecture of FIG. 9, the software architecture 906 may be conceptualized as a stack of layers where each layer provides particular functionality. For example, the software architecture 906 may include layers such as an operating system 902, libraries 920, frameworks/middleware 918, applications 916, and a presentation layer 914. Operationally, the applications 916 and/or other components within the layers may invoke API calls 908 through

the software stack and receive messages **912** in response to the API calls **908**. The layers illustrated are representative in nature and not all software architectures have all layers. For example, some mobile or special purpose operating systems may not provide a frameworks/middleware **918**, while others may provide such a layer. Other software architectures may include additional or different layers.

The operating system **902** may manage hardware resources and provide common services. The operating system **902** may include, for example, a kernel **922**, services **924**, and drivers **926**. The kernel **922** may act as an abstraction layer between the hardware and the other software layers. For example, the kernel **922** may be responsible for memory management, processor management (e.g., scheduling), component management, networking, security settings, and so on. The services **924** may provide other common services for the other software layers. The drivers **926** are responsible for controlling or interfacing with the underlying hardware. For instance, the drivers **926** include display drivers, camera drivers, Bluetooth® drivers, flash memory drivers, serial communication drivers (e.g., Universal Serial Bus (USB) drivers), Wi-Fi® drivers, audio drivers, power management drivers, and so forth depending on the hardware configuration.

The libraries **920** provide a common infrastructure that is used by the applications **916** and/or other components and/or layers. The libraries **920** provide functionality that allows other software components to perform tasks in an easier fashion than to interface directly with the underlying operating system **902** functionality (e.g., kernel **922**, services **924** and/or drivers **926**). The libraries **920** may include system libraries **944** (e.g., C standard library) that may provide functions such as memory allocation functions, string manipulation functions, mathematical functions, and the like. In addition, the libraries **920** may include API libraries **946** such as media libraries (e.g., libraries to support presentation and manipulation of various media format such as MPREG4, H.264, MP3, AAC, AMR, JPG, PNG), graphics libraries (e.g., an OpenGL framework that may be used to render two-dimensional and three-dimensional in a graphic content on a display), database libraries (e.g., SQLite that may provide various relational database functions), web libraries (e.g., WebKit that may provide web browsing functionality), and the like. The libraries **920** may also include a wide variety of other libraries **948** to provide many other APIs to the applications **916** and other software components/modules.

The frameworks/middleware **918** (also sometimes referred to as middleware) provide a higher-level common infrastructure that may be used by the applications **916** and/or other software components/modules. For example, the frameworks/middleware **918** may provide various graphic UI (GUI) functions, high-level resource management, high-level location services, and so forth. The frameworks/middleware **918** may provide a broad spectrum of other APIs that may be utilized by the applications **916** and/or other software components/modules, some of which may be specific to a particular operating system **902** or platform.

The applications **916** include built-in applications **938** and/or third-party applications **940**. Examples of representative built-in applications **938** may include, but are not limited to, a contacts application, a browser application, a book reader application, a location application, a media application, a messaging application, and/or a game application. Third-party applications **940** may include an application developed using the ANDROID™ or IOS™ software

development kit (SDK) by an entity other than the vendor of the particular platform, and may be mobile software running on a mobile operating system such as IOS™, ANDROID™, WINDOWS® Phone, or other mobile operating systems. The third-party applications **940** may invoke the API calls **908** provided by the mobile operating system (such as operating system **902**) to facilitate functionality described herein.

The applications **916** may use built-in operating system functions (e.g., kernel **922**, services **924**, and/or drivers **926**), libraries **920**, and frameworks/middleware **918** to create UIs to interact with users of the system. Alternatively, or additionally, in some systems, interactions with a user may occur through a presentation layer, such as presentation layer **914**. In these systems, the application/component “logic” can be separated from the aspects of the application/component that interact with a user.

FIG. **10** is a block diagram illustrating components of a machine **1000**, according to some example embodiments, able to read instructions from a machine-readable medium (e.g., a machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, FIG. **10** shows a diagrammatic representation of the machine **1000** in the example form of a computer system, within which instructions **1010** (e.g., software, a program, an application, an applet, an app, or other executable code) for causing the machine **1000** to perform any one or more of the methodologies discussed herein may be executed. As such, the instructions **1010** may be used to implement modules or components described herein. The instructions **1010** transform the general, non-programmed machine **1000** into a particular machine **1000** programmed to carry out the described and illustrated functions in the manner described. In alternative embodiments, the machine **1000** operates as a standalone device or may be coupled (e.g., networked) to other machines. In a networked deployment, the machine **1000** may operate in the capacity of a server machine or a client machine in a server-client network environment, or as a peer machine in a peer-to-peer (or distributed) network environment. The machine **1000** may comprise, but not be limited to, a server computer, a client computer, a personal computer (PC), a tablet computer, a laptop computer, a netbook, a set-top box (STB), a personal digital assistant (PDA), an entertainment media system, a cellular telephone, a smart phone, a mobile device, a wearable device (e.g., a smart watch), a smart home device (e.g., a smart appliance), other smart devices, a web appliance, a network router, a network switch, a network bridge, or any machine capable of executing the instructions **1010**, sequentially or otherwise, that specify actions to be taken by machine **1000**. Further, while only a single machine **1000** is illustrated, the term “machine” shall also be taken to include a collection of machines that individually or jointly execute the instructions **1010** to perform any one or more of the methodologies discussed herein.

The machine **1000** may include processors **1004**, memory/storage **1006**, and I/O components **1018**, which may be configured to communicate with each other such as via a bus **1002**. In an example embodiment, the processors **1004** (e.g., a central processing unit (CPU), a reduced instruction set computing (RISC) processor, a complex instruction set computing (CISC) processor, a graphics processing unit (GPU), a digital signal processor (DSP), an application-specific integrated circuit (ASIC), a radio-frequency integrated circuit (RFIC), another processor, or any suitable combination thereof) may include, for example, a processor **1008** and a processor **1012** that may execute the

instructions **1010**. The term “processor” is intended to include multi-core processors **1004** that may comprise two or more independent processors (sometimes referred to as “cores”) that may execute instructions contemporaneously. Although FIG. **10** shows multiple processors **1004**, the machine **1000** may include a single processor with a single core, a single processor with multiple cores (e.g., a multi-core processor), multiple processors with a single core, multiple processors with multiple cores, or any combination thereof.

The memory/storage **1006** may include a memory **1014**, such as a main memory, or other memory storage, and a storage unit **1016**, both accessible to the processors **1004** such as via the bus **1002**. The storage unit **1016** and memory **1014** store the instructions **1010** embodying any one or more of the methodologies or functions described herein. The instructions **1010** may also reside, completely or partially, within the memory **1014**, within the storage unit **1016**, within at least one of the processors **1004** (e.g., within the processor’s cache memory), or any suitable combination thereof, during execution thereof by the machine **1000**. Accordingly, the memory **1014**, the storage unit **1016**, and the memory of processors **1004** are examples of machine-readable media.

The I/O components **1018** may include a wide variety of components to receive input, provide output, produce output, transmit information, exchange information, capture measurements, and so on. The specific I/O components **1018** that are included in a particular machine **1000** will depend on the type of machine. For example, portable machines such as mobile phones will likely include a touch input device or other such input mechanisms, while a headless server machine will likely not include such a touch input device. It will be appreciated that the I/O components **1018** may include many other components that are not shown in FIG. **10**. The I/O components **1018** are grouped according to functionality merely for simplifying the following discussion and the grouping is in no way limiting. In various example embodiments, the I/O components **1018** may include output components **1026** and input components **1028**. The output components **1026** may include visual components (e.g., a display such as a plasma display panel (PDP), a light emitting diode (LED) display, a liquid crystal display (LCD), a projector, or a cathode ray tube (CRT)), acoustic components (e.g., speakers), haptic components (e.g., a vibratory motor, resistance mechanisms), other signal generators, and so forth. The input components **1028** may include alphanumeric input components (e.g., a keyboard, a touch screen configured to receive alphanumeric input, a photo-optical keyboard, or other alphanumeric input components), point-based input components (e.g., a mouse, a touchpad, a trackball, a joystick, a motion sensor, or other pointing instrument), tactile input components (e.g., a physical button, a touch screen that provides location and/or force of touches or touch gestures, or other tactile input components), audio input components (e.g., a microphone), and the like.

In further example embodiments, the I/O components **1018** may include biometric components **1039**, motion components **1034**, environmental components **1036**, or position components **1038** among a wide array of other components. For example, the biometric components **1039** may include components to detect expressions (e.g., hand expressions, facial expressions, vocal expressions, body gestures, or eye tracking), measure biosignals (e.g., blood pressure, heart rate, body temperature, perspiration, or brain waves), identify a person (e.g., voice identification, retinal identifi-

cation, facial identification, fingerprint identification, or electroencephalogram based identification), and the like. The motion components **1034** may include acceleration sensor components (e.g., accelerometer), gravitation sensor components, rotation sensor components (e.g., gyroscope), and so forth. The environmental components **1036** may include, for example, illumination sensor components (e.g., photometer), temperature sensor components (e.g., one or more thermometer that detect ambient temperature), humidity sensor components, pressure sensor components (e.g., barometer), acoustic sensor components (e.g., one or more microphones that detect background noise), proximity sensor components (e.g., infrared sensors that detect nearby objects), gas sensors (e.g., gas detection sensors to detection concentrations of hazardous gases for safety or to measure pollutants in the atmosphere), or other components that may provide indications, measurements, or signals corresponding to a surrounding physical environment. The position components **1038** may include location sensor components (e.g., a GPS receiver component), altitude sensor components (e.g., altimeters or barometers that detect air pressure from which altitude may be derived), orientation sensor components (e.g., magnetometers), and the like.

Communication may be implemented using a wide variety of technologies. The I/O components **1018** may include communication components **1040** operable to couple the machine **1000** to a network **1037** or devices **1029** via coupling **1024** and coupling **1022**, respectively. For example, the communication components **1040** may include a network interface component or other suitable device to interface with the network **1037**. In further examples, communication components **1040** may include wired communication components, wireless communication components, cellular communication components, Near Field Communication (NFC) components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components to provide communication via other modalities. The devices **1029** may be another machine or any of a wide variety of peripheral devices (e.g., a peripheral device coupled via a USB).

Moreover, the communication components **1040** may detect identifiers or include components operable to detect identifiers. For example, the communication components **1040** may include Radio Frequency Identification (RFID) tag reader components, NFC smart tag detection components, optical reader components (e.g., an optical sensor to detect one-dimensional bar codes such as Universal Product Code (UPC) bar code, multi-dimensional bar codes such as Quick Response (QR) code, Aztec code, Data Matrix, Data-glyph, MaxiCode, PDF417, Ultra Code, UCC RSS-2D bar code, and other optical codes), or acoustic detection components (e.g., microphones to identify tagged audio signals). In addition, a variety of information may be derived via the communication components **1040**, such as, location via Internet Protocol (IP) geo-location, location via Wi-Fi® signal triangulation, location via detecting a NFC beacon signal that may indicate a particular location, and so forth.

Glossary

“CARRIER SIGNAL” in this context refers to any intangible medium that is capable of storing, encoding, or carrying transitory or non-transitory instructions for execution by the machine, and includes digital or analog communications signals or other intangible medium to facilitate communication of such instructions. Instructions may be transmitted or received over the network using a transitory or

non-transitory transmission medium via a network interface device and using any one of a number of well-known transfer protocols.

“CLIENT DEVICE” in this context refers to any machine that interfaces to a communications network to obtain resources from one or more server systems or other client devices. A client device may be, but is not limited to, a mobile phone, desktop computer, laptop, PDAs, smart phones, tablets, ultra books, netbooks, laptops, multi-processor systems, microprocessor-based or programmable consumer electronics, game consoles, set-top boxes, or any other communication device that a user may use to access a network.

“COMMUNICATIONS NETWORK” in this context refers to one or more portions of a network that may be an ad hoc network, an intranet, an extranet, a virtual private network (VPN), a local area network (LAN), a wireless LAN (WLAN), a wide area network (WAN), a wireless WAN (WWAN), a metropolitan area network (MAN), the Internet, a portion of the Internet, a portion of the Public Switched Telephone Network (PSTN), a plain old telephone service (POTS) network, a cellular telephone network, a wireless network, a Wi-Fi® network, another type of network, or a combination of two or more such networks. For example, a network or a portion of a network may include a wireless or cellular network and the coupling may be a Code Division Multiple Access (CDMA) connection, a Global System for Mobile communications (GSM) connection, or other type of cellular or wireless coupling. In this example, the coupling may implement any of a variety of types of data transfer technology, such as Single Carrier Radio Transmission Technology (1×RTT), Evolution-Data Optimized (EVDO) technology, General Packet Radio Service (GPRS) technology, Enhanced Data rates for GSM Evolution (EDGE) technology, third Generation Partnership Project (3GPP) including 3G, fourth generation wireless (4G) networks, Universal Mobile Telecommunications System (UMTS), High Speed Packet Access (HSPA), Worldwide Interoperability for Microwave Access (WiMAX), Long Term Evolution (LTE) standard, others defined by various standard setting organizations, other long range protocols, or other data transfer technology.

“EPHEMERAL MESSAGE” in this context refers to a message that is accessible for a time-limited duration. An ephemeral message may be a text, an image, a video, and the like. The access time for the ephemeral message may be set by the message sender. Alternatively, the access time may be a default setting or a setting specified by the recipient. Regardless of the setting technique, the message is transitory.

“MACHINE-READABLE MEDIUM” in this context refers to a component, device, or other tangible media able to store instructions and data temporarily or permanently and may include, but is not limited to, random-access memory (RAM), read-only memory (ROM), buffer memory, flash memory, optical media, magnetic media, cache memory, other types of storage (e.g., Erasable Programmable Read-Only Memory (EEPROM)) and/or any suitable combination thereof. The term “machine-readable medium” should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, or associated caches and servers) able to store instructions. The term “machine-readable medium” shall also be taken to include any medium, or combination of multiple media, that is capable of storing instructions (e.g., code) for execution by a machine, such that the instructions, when executed by one or more processors of the machine, cause the machine

to perform any one or more of the methodologies described herein. Accordingly, a “machine-readable medium” refers to a single storage apparatus or device, as well as “cloud-based” storage systems or storage networks that include multiple storage apparatus or devices. The term “machine-readable medium” excludes signals per se.

“COMPONENT” in this context refers to a device, physical entity, or logic having boundaries defined by function or subroutine calls, branch points, APIs, or other technologies that provide for the partitioning or modularization of particular processing or control functions. Components may be combined via their interfaces with other components to carry out a machine process. A component may be a packaged functional hardware unit designed for use with other components and a part of a program that usually performs a particular function of related functions. Components may constitute either software components (e.g., code embodied on a machine-readable medium) or hardware components. A “hardware component” is a tangible unit capable of performing certain operations and may be configured or arranged in a certain physical manner. In various example embodiments, one or more computer systems (e.g., a stand-alone computer system, a client computer system, or a server computer system) or one or more hardware components of a computer system (e.g., a processor or a group of processors) may be configured by software (e.g., an application or application portion) as a hardware component that operates to perform certain operations as described herein.

A hardware component may also be implemented mechanically, electronically, or any suitable combination thereof. For example, a hardware component may include dedicated circuitry or logic that is permanently configured to perform certain operations. A hardware component may be a special-purpose processor, such as a Field-Programmable Gate Array (FPGA) or an ASIC. A hardware component may also include programmable logic or circuitry that is temporarily configured by software to perform certain operations. For example, a hardware component may include software executed by a general-purpose processor or other programmable processor. Once configured by such software, hardware components become specific machines (or specific components of a machine) uniquely tailored to perform the configured functions and are no longer general-purpose processors. It will be appreciated that the decision to implement a hardware component mechanically, in dedicated and permanently configured circuitry, or in temporarily configured circuitry (e.g., configured by software) may be driven by cost and time considerations. Accordingly, the phrase “hardware component” (or “hardware-implemented component”) should be understood to encompass a tangible entity, be that an entity that is physically constructed, permanently configured (e.g., hardwired), or temporarily configured (e.g., programmed) to operate in a certain manner or to perform certain operations described herein. Considering embodiments in which hardware components are temporarily configured (e.g., programmed), each of the hardware components need not be configured or instantiated at any one instance in time. For example, where a hardware component comprises a general-purpose processor configured by software to become a special-purpose processor, the general-purpose processor may be configured as respectively different special-purpose processors (e.g., comprising different hardware components) at different times. Software accordingly configures a particular processor or processors, for example, to constitute a particular hardware component at one instance of time and to constitute a different hardware component at a different instance of time.

Hardware components can provide information to, and receive information from, other hardware components. Accordingly, the described hardware components may be regarded as being communicatively coupled. Where multiple hardware components exist contemporaneously, communications may be achieved through signal transmission (e.g., over appropriate circuits and buses) between or among two or more of the hardware components. In embodiments in which multiple hardware components are configured or instantiated at different times, communications between such hardware components may be achieved, for example, through the storage and retrieval of information in memory structures to which the multiple hardware components have access. For example, one hardware component may perform an operation and store the output of that operation in a memory device to which it is communicatively coupled. A further hardware component may then, at a later time, access the memory device to retrieve and process the stored output.

Hardware components may also initiate communications with input or output devices, and can operate on a resource (e.g., a collection of information). The various operations of example methods described herein may be performed, at least partially, by one or more processors that are temporarily configured (e.g., by software) or permanently configured to perform the relevant operations. Whether temporarily or permanently configured, such processors may constitute processor-implemented components that operate to perform one or more operations or functions described herein. As used herein, “processor-implemented component” refers to a hardware component implemented using one or more processors. Similarly, the methods described herein may be at least partially processor-implemented, with a particular processor or processors being an example of hardware. For example, at least some of the operations of a method may be performed by one or more processors or processor-implemented components. Moreover, the one or more processors may also operate to support performance of the relevant operations in a “cloud computing” environment or as a “software as a service” (SaaS). For example, at least some of the operations may be performed by a group of computers (as examples of machines including processors), with these operations being accessible via a network (e.g., the Internet) and via one or more appropriate interfaces (e.g., an API). The performance of certain of the operations may be distributed among the processors, not only residing within a single machine, but deployed across a number of machines. In some example embodiments, the processors or processor-implemented components may be located in a single geographic location (e.g., within a home environment, an office environment, or a server farm). In other example embodiments, the processors or processor-implemented components may be distributed across a number of geographic locations.

“PROCESSOR” in this context refers to any circuit or virtual circuit (a physical circuit emulated by logic executing on an actual processor) that manipulates data values according to control signals (e.g., “commands,” “op codes,” “machine code,” etc.) and which produces corresponding output signals that are applied to operate a machine. A processor may, for example, be a Central Processing Unit (CPU), a Reduced Instruction Set Computing (RISC) processor, a Complex Instruction Set Computing (CISC) processor, a Graphics Processing Unit (GPU), a Digital Signal Processor (DSP), an ASIC, a Radio-Frequency Integrated Circuit (RFIC) or any combination thereof. A processor may further be a multi-core processor having two or more

independent processors (sometimes referred to as “cores”) that may execute instructions contemporaneously.

“TIMESTAMP” in this context refers to a sequence of characters or encoded information identifying when a certain event occurred, for example giving date and time of day, sometimes accurate to a small fraction of a second.

Changes and modifications may be made to the disclosed embodiments without departing from the scope of the present disclosure. These and other changes or modifications are intended to be included within the scope of the present disclosure, as expressed in the following claims.

What is claimed is:

1. A method comprising:

receiving, by one or more processors, a monocular image that includes a depiction of a body of a user;

identifying features for a plurality of skeletal joints of the monocular image using a first machine learning technique, wherein positions of a plurality of skeletal joints are detected based on the identified plurality of skeletal joint features;

filtering the plurality of skeletal joints of the body detected based on the monocular image using one or more images of the user received prior to receiving the monocular image; and

rendering display of one or more virtual objects in the monocular image based on the filtered plurality of skeletal joints of the body.

2. The method of claim 1, further comprising:

detecting a plurality of skeletal joints of the body based on the monocular image;

accessing a video feed comprising the one or more images received prior to the monocular image to filter the plurality of skeletal joints of the body; and

determining a pose represented by the body depicted in the monocular image based on the filtered plurality of skeletal joints of the body.

3. The method of claim 1, further comprising:

modifying a pose of an avatar to match a pose represented by the body depicted in the monocular image by adjusting a set of skeletal joints of a rig of an avatar based on the filtered plurality of skeletal joints of the body; and

generating, for display, the avatar having the modified pose that matches the pose represented by the body depicted in the monocular image.

4. The method of claim 1, wherein the monocular image is a first frame of a video, and wherein the first machine learning technique comprises a first deep neural network.

5. The method of claim 4, further comprising training the first deep neural network by performing operations comprising:

receiving training data comprising a plurality of training monocular images and ground truth skeletal joint information for each of the plurality of training monocular images, each of the plurality of training monocular images depicting a different body pose;

applying the first deep neural network to a first training monocular image of the plurality of training monocular images to estimate skeletal joints of the body depicted in the first training monocular image;

computing a deviation between the estimated skeletal joints of the body and the ground truth skeletal joint information associated with the first training monocular image;

updating parameters of the first deep neural network based on the computed deviation; and

repeating the applying, computing and updating steps for each of the plurality of training monocular images.

6. The method of claim 1, wherein filtering the plurality of skeletal joints comprises applying a video feed to a second machine learning technique to estimate skeletal joint positions.

7. The method of claim 6, wherein the second machine learning technique comprises a second deep neural network, and wherein the filtering comprises comparing a prediction of the skeletal joint positions for the monocular image provided by the second deep neural network with the plurality of skeletal joint features of the monocular image identified using a first machine learning technique.

8. The method of claim 7, further comprising training the second deep neural network by performing operations comprising:

receiving training data comprising a plurality of training videos and ground truth skeletal joint information for each of the plurality of training videos, each of the plurality of training videos depicting a different body pose;

applying the second deep neural network to a first training video of the plurality of training videos to predict skeletal joints of the body in a frame subsequent to the first training video;

computing a deviation between the predicted skeletal joints of the body and the ground truth skeletal joint information associated with the first training video;

updating parameters of the second deep neural network based on the computed deviation; and

repeating the applying, computing and updating steps for each of the plurality of training videos.

9. The method of claim 1, wherein the one or more images were received a threshold number of seconds prior to receiving the monocular image.

10. The method of claim 1, further comprising selecting an avatar associated with a rig from a plurality of avatars.

11. The method of claim 1, further comprising:

receiving a second video comprising a plurality of monocular images that include the depiction of the body of the user;

tracking changes in the plurality of skeletal joints across the plurality of monocular images;

detecting changes to a pose represented by the body based on tracking the changes in the plurality of skeletal joints; and

continuously or periodically modifying poses of an avatar to match the changes to the pose represented by the body.

12. The method of claim 1, further comprising causing an avatar to interact with a virtual object depicted in a given image.

13. The method of claim 1, wherein identifying and filtering are performed without accessing depth information from a depth sensor.

14. The method of claim 1, wherein detecting the plurality of skeletal joints of the body comprises identifying points respectively associated with a right wrist, a right elbow, a right shoulder, a nose on a face of the user, a left shoulder, a left elbow, and a left wrist.

15. The method of claim 1, wherein a rate at which the plurality of skeletal joints is detected is adjusted based on a position of the user relative to an image capture device.

16. A system comprising:

a processor configured to perform operations comprising: receiving a monocular image that includes a depiction of a body of a user;

identifying features for a plurality of skeletal joints of the monocular image using a first machine learning technique, wherein positions of a plurality of skeletal joints are detected based on the identified plurality of skeletal joint features;

filtering the plurality of skeletal joints of the body detected based on the monocular image using one or more images of the user received prior to receiving the monocular image; and

rendering display of one or more virtual objects in the monocular image based on the filtered plurality of skeletal joints of the body.

17. The system of claim 16, wherein the operations further comprise:

detecting a plurality of skeletal joints of the body based on the monocular image;

accessing a video feed comprising the one or more images received prior to the monocular image to filter the plurality of skeletal joints of the body; and

determining a pose represented by the body depicted in the monocular image based on the filtered plurality of skeletal joints of the body.

18. The system of claim 16, wherein the operations further comprise:

modifying a pose of an avatar to match a pose represented by the body depicted in the monocular image by adjusting a set of skeletal joints of a rig of an avatar based on the filtered plurality of skeletal joints of the body; and

generating, for display, the avatar having the modified pose that matches the pose represented by the body depicted in the monocular image.

19. A non-transitory machine-readable storage medium that includes instructions that, when executed by one or more processors of a machine, cause the machine to perform operations comprising:

receiving a monocular image that includes a depiction of a body of a user;

identifying features for a plurality of skeletal joints of the monocular image using a first machine learning technique, wherein positions of a plurality of skeletal joints are detected based on the identified plurality of skeletal joint features;

filtering the plurality of skeletal joints of the body detected based on the monocular image using one or more images of the user received prior to receiving the monocular image; and

rendering display of one or more virtual objects in the monocular image based on the filtered plurality of skeletal joints of the body.

20. The non-transitory machine-readable medium of claim 19, wherein the operations further comprise:

detecting a plurality of skeletal joints of the body based on the monocular image;

accessing a video feed comprising the one or more images received prior to the monocular image to filter the plurality of skeletal joints of the body; and

determining a pose represented by the body depicted in the monocular image based on the filtered plurality of skeletal joints of the body.